UNIVERSITY OF ALBERTA

DINOFLAGELLATES AND ACRITARCHS FROM THE BEARPAW FORMATION, SOUTHERN ALBERTA

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Dinoflagellates and Acritarchs from the Bearpaw Formation, Southern Alberta", submitted by Rex Harland, B.Sc. (Hons)., M.Sc., F.G.S., in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

July 1970.

To My Wife

ABSTRACT

Fifty-two species of dinoflagellate cysts belonging to the Cyst-Families Gonyaulacystaceae, Pareodiniaceae, Microdiniaceae, Fromeaceae, Canningiaceae, Pyxidiellaceae, Hystrichosphaeridiaceae, Exochosphaeridiaceae, Areoligeraceae, Spiniferitiaceae, Deflandreaceae, Hexagoniferaceae and Pseudoceratiaceae; and siz species of acritarchs belonging to the Sub-groups Acanthomorphitae and Herkomorphitae have been described and figured from the upper Campanian Bearpaw Formation of the Cretaceous of southern Alberta. The following genera have been recorded:- Cribroperidinium, Pareodinia, Apteodinium, Diconodinium, Komewuia, Lejeunia, Spinidinium, Microdinium, Dinogymnium, ? Membranosphaera, Canningia, ? Uvatodinium, Hystrichosphaeridium, Cleistosphaeridium, ? Coronifera, Oligosphaeridium, Polysphaeridium, Tanyosphaeridium, Exochosphaeridium, Cyclonephelium, Spiniferites, Achomosphaera, Deflandrea, Hexagonifera, Odontochitina, Baltisphaeridium, Micrhystridium, and Cymatiosphaera.

A morphological classification has been used in the systematic descriptions of these microplankton, but natural affinities have been noted where known or reasonably assured.

Full descriptions have been given of the biology of the modern representatives of the Pyrrhophyta, and of the morphology of the fossil representatives.

The sampling and laboratory techniques have been presented and full descriptions of the various stratigraphic sections sampled, have also been included.

Using the recovered dinoflagellates and acritarchs, the Bearpaw Formation, in southern Alberta, has been divided into three informal assemblage zones, that are designated I to III.

Range charts have been drawn to show the ranges of the various dinoflagellate cysts and acritarchs for the Lethbridge and Cypress Hills areas, and to show the stratigraphic positions of the erected assemblage zones in these two areas.

A parameter called the gonyaulacacean ratio, which relates the proportions of gonyaulacacean cysts to those of peridiniacean cysts, was used as a passible guide to the salinity of the Bearpaw sea. This has been interpreted to show the presence of two periods, and two sub-periods of open marine conditions during the presence of the Bearpaw sea in southern Alberta. These open marine conditions are intimately connected with the assemblage zones erected for the formation. The salinity fluctuations may be the result of large volumes of freshwater being discharged into the sea, may be the result of differences in the proximity of the shoreline or may be a combination of these and other factors.

ACKNOWLEDGEMENTS

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Frontispiece: Lejeunia tricuspis (Wetzel) comb. nov. x c. 1100 Manyberries Member, Bearpaw Formation: southern Alberta.

CHAPTER I

INTRODUCTION

The palynology of the western Canadian sedimentary basin is still in its initial stages, especially with regard to the study of Upper Cretaceous organic-walled microplankton. To the author's knowledge there are only three published papers dealing exclusively with the Upper Cretaceous microplankton of Canada, two of which are concerned with the Cenomanian of Saskatchewan (Davey 1969a, 1970) and the other with the Upper Cretaceous of the Arctic Islands (Manum & Cookson 1964). In contrast a number of papers have been published on the microplankton of the Australian Upper Cretaceous by Cookson (1955, 1965), Cookson & Eisenack (1958, 1960, 1961, 1962) and Deflandre & Cookson (1955). Drugg (1967) published on Maestrichtian forms from California and Davey (op. cit.) and Clarke & Verdier (1967) published on the Upper Cretaceous microplankton from England. Vozzhennikova (1967) has published on Cretaceous forms from the U.S.S.R. Srivastava (1967) reviewed the papers of Cookson & Eisenack (op. cit.) in his account of Upper Cretaceous palynology. In addition Davey (1969b, 1969c) has recently published on the Upper Cretaceous of South Africa. Further references to Upper Cretaceous microplankton may be found in Downie & Sarjeant (1964).

Currently S.A.J. Pocock of Imperial Oil Limited (Calgary) is working on palynomorphs from the Cretaceous and Lower Tertiary of southern Alberta; D. J. McIntyre of Chevron Standard Limited (Calgary) is working on western Canadian palynomorphs; R. L. Cox of the Geological Survey of Canada is studying Albian-Campanian dinoflagellates from southern Saskatchewan and south-western Manitoba; G. Norris of the University of Toronto is working on Cretaceous palynomorphs from Alberta and C. Singh of the Research Council of Alberta is preparing a publication on Lower Cretaceous palynomorphs from Alberta (Staplin 1969b).

[illegible]

In recent years a number of major advances have been made in our knowledge of the relationship of the dinoflagellate cyst to the dinoflagellate life cycle (Evitt 1961, Evitt & Davidson 1964, Wall 1965 and Wall & Dale, 1967, 1968a, 1968b, 1968c, 1969, 1970). Using these works it is now possible to assign certain fossil dinoflagellate cysts to their natural families.

The microplankton described within are classified using the morphological scheme of Sarjeant & Downie (1966) for the dinoflagellate cysts and that of Downie et al. (1963) for the acritarchs. Most of the dinoflagellate cysts of this thesis can, however, be related to their thecal stage using such features as tabulation, process arrangement and the position of the archeopyle. The natural orientation of the cysts is described where possible and is so portrayed in the figures of the specimens.

It was decided that, in this initial study of western Canadian Upper Cretaceous microplankton, samples should be collected from a formation that is firmly placed in the geological time scale. The Bearpaw Formation is such a unit. The Bearpaw consists of a dark marine shale with subordinate sands and bentonite horizons. It is fossiliferous and has been placed in the upper Campanian by virtue of its ammonite faunas. It is one of the few sedimentary units that have been accurately dated using radiometric means. Since the Bearpaw strata of southern Alberta are best known from Lethbridge and the Cypress Hills, assemblages from these two areas were picked for study (Figure 1). A certain amount of associated foraminiferal data was also available for the formation in the Lethbridge area (Anan-Yorke 1969), and many of the samples used in the present study are aliquots of Anan-Yorke's original samples.

Comparative studies on the microplankton of the Campanian Bearpaw Formation of southern Alberta are handicapped, however, by the overall lack of published information on Campanian microplankton from Canada and from other countries of the world. Only those papers of Clarke & Verdier (1967), Cookson & Eisenack (1960), Vozzhennikova (1967) and Davey (1969b, 1969c) deal in any

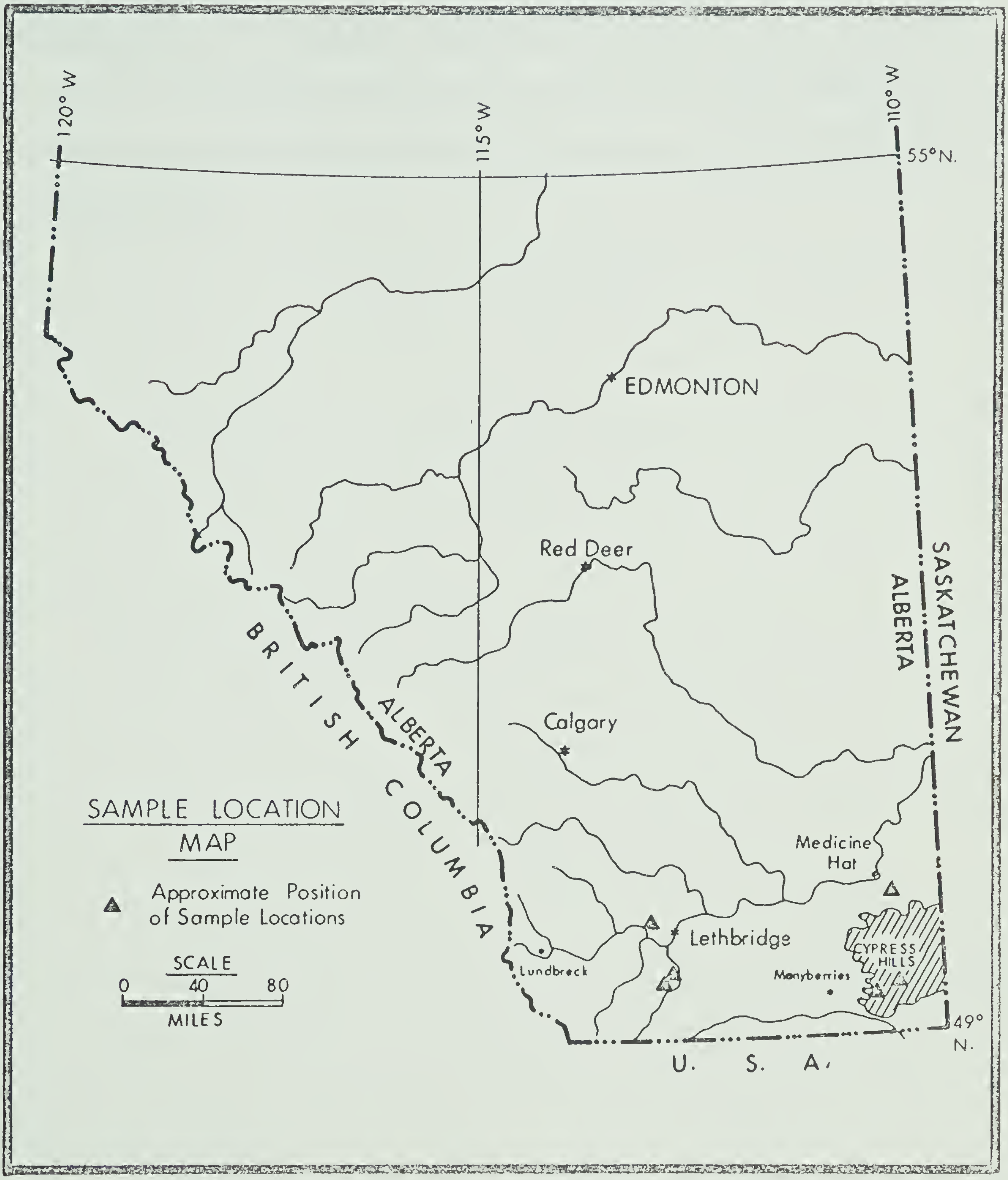

Figure I: Sketch map of southern Alberta showing the approximate positions of the sample localities.

detail with Campanian microplankton.

This study of the microplankton of the Bearpaw Formation is the first full taxonomic account of a microplankton assemblage from Canada, and constitutes a pioneer study of a Campanian assemblage using modern taxonomic approaches. It is also an encouraging utilization of the work of Wall & Dale (1968a) in the reconstruction of the palaeoenvironment of the Bearpaw sea from dinoflagellate cyst populations.

CHAPTER II

STRATIGRAPHY OF THE BEARPAW FORMATION

Previous Work

The Bearpaw Formation was named in 1903 by J. B. Hatcher & T. W. Stanton from localities in the vicinity of the Bearpaw Mountains, north-central Montana. In 1905 Stanton & Hatcher published an extended account of the formation noting the typical lithology of dark shales with ironstone concretions. The authors were mainly interested in the Montant type-area but extended their study to include southern Alberta and Saskatchewan.

Dowling (1917), Williams & Dyer (1930), Link & Childerhose (1931), Clark (1931), Yarwood (1931), Warren (1931), Wickenden (1932) and Fraser *et al*. (1935) all contributed to the knowledge of the stratigraphy and palaeontology of the Bearpaw Formation in the earlier half of this century.

The first biostratigraphic zonation was that of Russell & Landes (1940), for a section of the formation exposed at Manyberries, southern Alberta (see Figure 1). The zonation was based on ammonite and pelecypod faunas; the presence of *Baculites compressus* Say and *Acanthoscaphites nodosus* Owen enabled the authors to correlate the formation with the Campanian Stage of the Upper Cretaceous.

In 1947 Lines presented a paper before the Alberta Association of Petroleum Geologists that became a standard reference for the formation. Formal stratigraphic names of member rank were introduced and have been accepted into the nomenclature of Alberta stratigraphy despite delayed publication. (Lines' paper was published posthumously in 1963).

Furnival (1950), Russell (1950), Crockford (1951), Loranger & Gleddie (1953) and Byrne & Farvolden (1959) published on various aspects of the Bearpaw Formation. Loranger & Gleddie (op. cit.) were, however, the first to attempt a micropaleontological zonation using ostracods and foraminiferids.

Radiometric dates, using the potassium-argon method, became available for the Bearpaw Formation in the early 1960's with 75 ± 4 million years being published as the date of a thin seam of bentonite 65 feet above the base of the formation at Lethbridge (Folinsbee et al. 1960, 1961). In 1965 Folinsbee et al. published additional data indicating that the base of the formation in southern Alberta is approximately "isochronous", with the rapid transgression of the Bearpaw sea 72-73 million years ago.

A review of the Bearpaw Formation in western Canada appeared in Williams & Burk (1964) and a foraminiferal zonation for the formation in south-western Saskatchewan was published by Caldwell & North (1964). The relationship of the formation to the macrofossil zonation of the marine Cretaceous of western Canada has been recently determined by Jeletzky (1967), extending the work of Cobban and Reeside (1952).

Caldwell (1968) in describing the Bearpaw Formation of the South Saskatchewan River valley in Saskatchewan, recognised two broad faunal assemblages and a time span for the formation from Late Campanian to Early Maestrichtian. Given (1969) and Anan-Yorke (1969) have recently completed foraminiferal work on the formation but as yet this information is unpublished.

General Description of the Bearpaw Formation

The Bearpaw Formation is for the most part a sub-horizontal unit except where it has been affected by the Sweetgrass Arch uplift. This led to the subsequent erosion of the formation from the crest of the arch (Williams & Dyer 1930) such that the outcrop pattern of the formation in Canada is mainly divided into a smaller western area and a larger eastern area. The formation is also exposed in the foothills of the Canadian Rocky Mountains at Lundbreck, south-western Alberta (see Figure 1) where it is disturbed by folding and faulting.

The formation rests conformably upon the Oldman Formation both in its eastern outcrop area near the Cypress Hills of south-eastern Alberta and in its western outcrop area near Lethbridge. It rests conformably upon the Judith River Formation in the type area. The formation is conformably overlain by the St. Mary River, Eastend and Fox Hills Formations in the Lethbridge, Cypress Hills and Montana outcrop areas respectively.

A maximum thickness of 1170 feet has been recorded for the Bearpaw Formation in the Cypress Hills (Lines, 1947, in litt. 1963), whereas at Lethbridge it is 726 feet thick (Link & Childerhose 1931) and in the vicinity of Edmonton a thickness of 100 feet or less has been reported (Williams & Burk 1964).

The lithology of the formation is predominantly one of shales with intercalated sandstones, minor bentonites, carbonate bands and concretionary ironstone nodule horizons. Detailed lithological descriptions are given by Williams & Dyer (1930), Link & Childerhose (1931), Russell & Landes (1940), Furnival (1950) and Caldwell (1968).

The base of the formation in southern Alberta is generally regarded as being isochronous (Lines, 1947 in litt. 1963) but it becomes diachronous to the north, as demonstrated by Given (1969), and to the east as shown by Caldwell (1968). To the north the lower boundary becomes younger and to the east it becomes older. The upper boundary is, however, markedly diachronous, as first suggested by Russell (1950), such that only the lower 600 feet of the formation in the Cypress Hills area is represented in south-western Alberta by marine strata. Folinsbee et al. (1965) have dated the lower boundary of the formation and using an extrapolated sedimentation rate (Folinsbee et al. 1961) have calculated that the Bearpaw sea began to withdraw from the western part of the Alberta basin about 68 million years ago and had completely withdrawn by 66 million years. A figure of 6 million years may then be calculated as the maximum duration of the Bearpaw sea in southern Alberta. Caldwell (1968), however, estimates that the formation in south-western Saskatchewan accumulated

between 74.5 and 70 million years ago. This discrepancy is due to differences in the estimation of sedimentation rates.

In international terms the age of the formation in southern Alberta is upper Campanian, for the most part lying within the Baculites compressus sensu lato Zone (Jeletzky 1968); (based largely on the work of Cobban & Reeside (1952) and Cobban (1962a, 1962b)). In terms of the zones as they stand today (Caldwell 1968) it lies within the zones of B. compressus sensu stricto, B. cuneatus, B. reesidei, B. jenseni and B. eliasi. Caldwell (1968), however, finds that his Saskatchewan section ranges from the pre-Exiteloceras jenneyi Zone to the zone of Baculites grandis.

Caldwell & North (1964) have divided the Bearpaw Formation of south-western Saskatchewan into three foraminiferal assemblage zones which have proved to be applicable to Alberta (Given 1969, Anan-Yorke 1969). These zones are listed below together with Caldwell and North's correlation with the zones of Loranger & Gleddie (1953) :-

1)- Haplophragmoides excavata Assemblage Zone = Ammodiscus and Gyroidina Zones of Loranger & Gleddie.

2)- Anomalinoides henbesti Assemblage Zone = Anomalina Zone of Loranger and Gleddie.

3)- Tentative zone characterised by Gaudryina sp. and Haplophragmoides spp. = Tritaxia crydermanensa and Plectina smithia zones of Loranger and Gleddie.

North & Caldwell (in press) have recently completed a foraminiferal study to complement Caldwell's description of the Bearpaw Formation of the South Saskatchewan River valley.

The faunal content of the Bearpaw Formation consists, in general, of molluscs, predominantly ammonites and bivalves; and foraminiferids, but full descriptions are given in a number of publications, notably Warren (in Fraser et al. 1935), Dowling (1917), Williams & Dyer (1930), Russell & Landes (1940), Warren (1931, 1934, 1937) and Douglas (1942). Caldwell (1968) gives an excellent review of the Baculites range zone fossils, rare invertebrate fossils and vertebrate fossils that have been recovered from the Bearpaw Formation.

The Bearpaw Formation was deposited in a littoral-neritic environment with a water depth probably nowhere exceeding 150 feet (Caldwell 1968). Foraminiferids from the formation were subject to a strong environmental control (Caldwell & North 1964). Brackish water foraminiferids have been described by Wickenden (1932), Loranger & Gleddie (1953) and Caldwell & North (op. cit.). Fluctuations of water depth and salinities have been reported by Anan-Yorke (1969). No deep water phases are recognised and salinity fluctuations are probably due to variations in run-off from the land surface.

The deposition of the Bearpaw Formation was accomplished during the last major marine transgression in western Canadian geological history (Warren & Stelck 1958). A connection with the Arctic is indicated by the work of Martin (1961) and Given (1969), in addition to a connection with the Gulf of Mexico (Reeside 1957). The sea finally retreated before the continuous growth of alluvial plains, the product of subaerial erosion from the newly uplifted Cordillera, in a slow and intermittent manner with occasional resurgence. Volcanic activity was also common giving rise to the many bentonite and ash beds within the Bearpaw and later formations. Nascimbene (1963) considers the area of vulcanicity to be in the eastern Cordilleran belt of northern Montana accompanying the gradual emplacement of the Boulder batholith.

Bearpaw Formation of Southern Alberta

Much of our present knowledge of the Bearpaw Formation in outcrop comes from two areas in southern Alberta - namely the area adjacent to Lethbridge and that in the immediate vicinity of the Cypress Hills, (see Figures 1, 2 and 3). Palynological samples were taken from these two areas as all sections are accessible and foraminiferal control is available (Anan-Yorke 1969, Loranger & Gleddie 1953, Caldwell & North 1964).

a) Lethbridge Area

The Bearpaw Formation of the Lethbridge area has been described by Link & Childerhose (1931). The formation is well exposed in the valley of the St. Mary River, especially in the cut bank sides of meanders. The formation rests conformably upon the "Lethbridge Coal Measures" of the Oldman Formation, the boundary being drawn at the top of a conspicuous brown ferruginous sandstone, 8 inches to 2 feet thick. The basal part of the formation consists of 15 feet of alternating laminae of fine grained sandstones and shales. These are termed the transition beds, and are succeeded by 200 feet of dark shales which become sandy toward the base of the Magrath Member. This member is 62 feet thick and consists of a light grey and greenish blue medium grained shaly sandstone. Concretions at the base of the Magrath Member are rich in specimens of Arctica ovata (Meek & Hayden). This part of the section contains a number of prominent bentonites which have been designated the letters "A" to "D" by Link & Childerhose (op. cit.). These beds are used extensively as marker horizons. Above the Magrath Member there are 100 feet of laminated dark shales followed by the Kipp Member. The Kipp Member, 90 feet thick, is a dense, coherent, greenish blue, fine grained shaly sandstone. Fossiliferous shale partings that yield Baculites ovatus Say and Placenticeras meeki Boehm, occur within this unit. Lying above the Kipp Member are 140 feet of dense, dark blue and grey shales with sand laminae and sandy shales; a number of ash beds and a glauconitic horizon also occur. The youngest

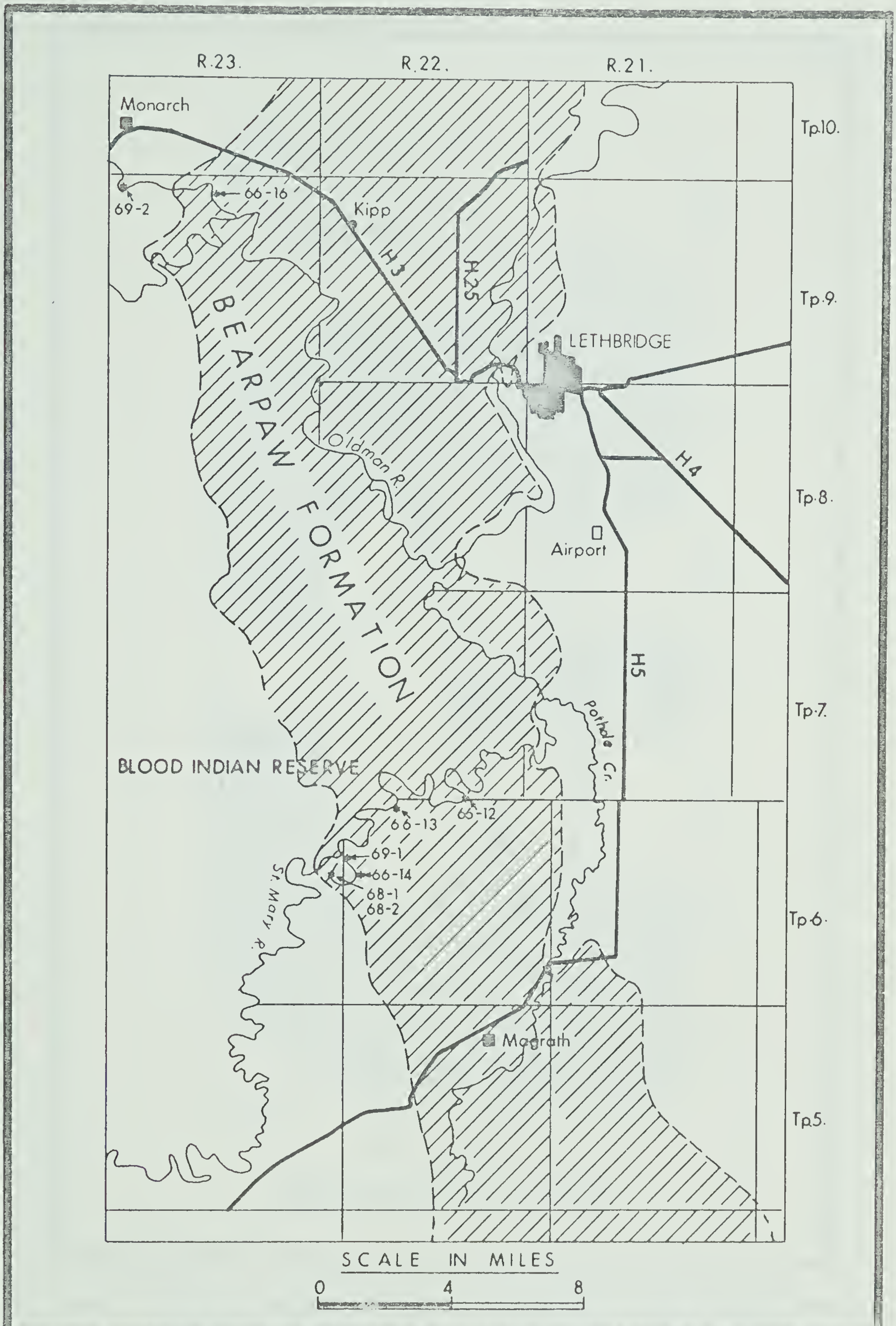

Figure 2: Detailed map of the Lethbridge area with the approximate outcrop pattern of the Bearpaw Formation and the positions of the sample localities. (Geology after G.S.C. Calgary Sheet 1928).

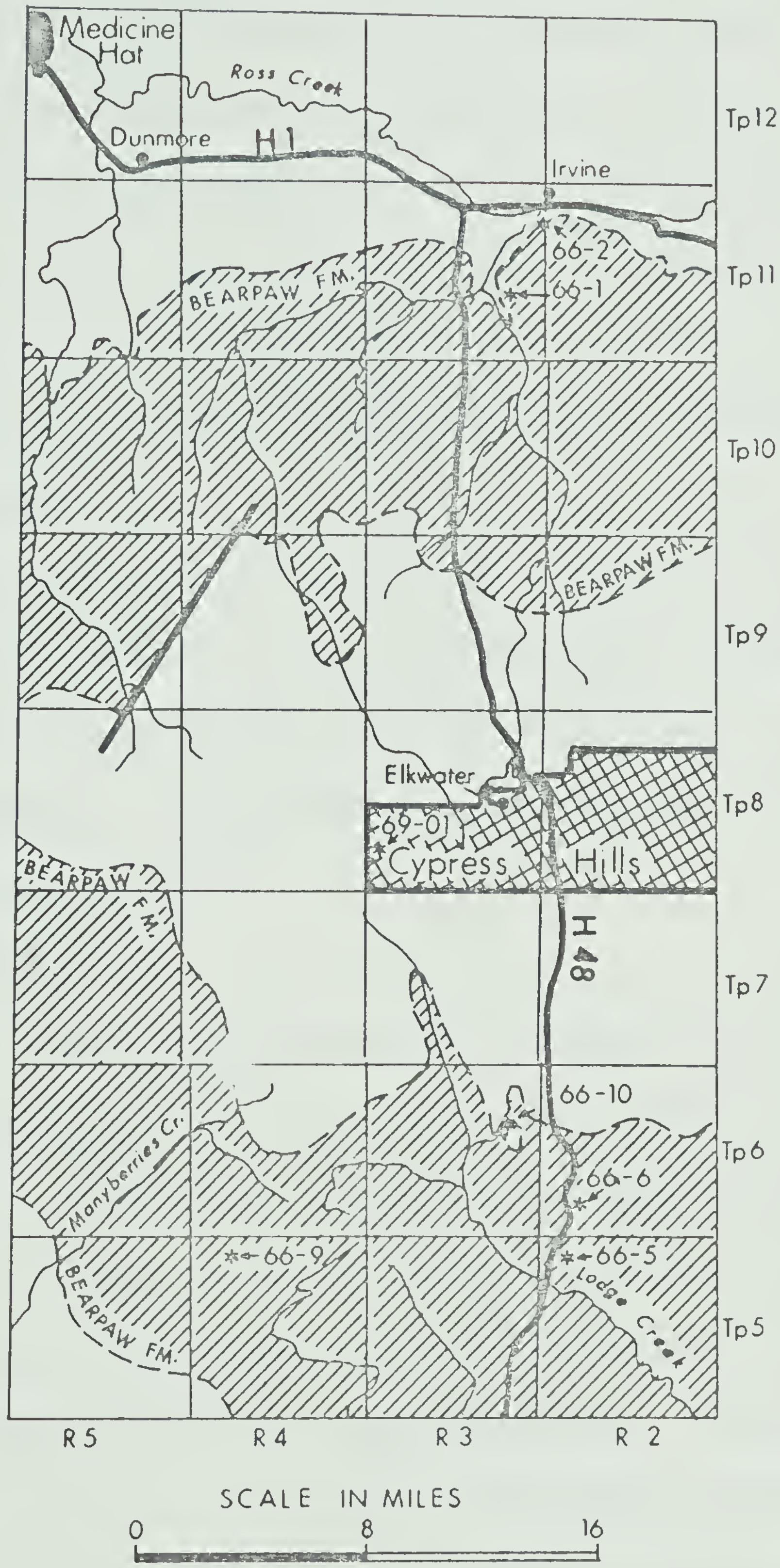

Figure 3: Detailed map of the Cypress Hills area with the approximate outcrop pattern of the Bearpaw Formation and the positions of the sample localities. (Geology after G. S. C. Calgary Sheet 1928).

member, the Ryegrass sandstone, succeeds the shale. It is 40 feet thick and consists of a lower section of coarse greenish sandstone with some shale, and an upper, comprising well bedded shales with some greenish blue sandstones. Above the Ryegrass Member are 95 feet of shales and 20 feet of transition beds of shaly sandstones and sandy shales before passage into the Blood Reserve sandstone. This unit is considered to be a member of the Bearpaw Formation by Loranger & Gleddie (1953) and Byrne & Farvolden (1959); to be a separate formation by Caldwell (1968) and Folinsbee et al. (1965), and has been included within the St. Mary River Formation by Russell (1932) and Williams & Burk (1964). In the present work it is considered discrete from the Bearpaw Formation.

The regional dip of the formation in the Lethbridge area is less than 10 degrees in a westerly direction. Locally, however, there are normal faults and open folds as seen as the Monarch locality (JW66-16 and RH69-16). A composite section of the Bearpaw Formation in the Lethbridge area is illustrated in Figure 4, and a detailed location map in Figure 2.

b) Cypress Hills Area

A palteau remnant, the Cypress Hills, is capped by the Cypress Hills Formation of Oligocene age and is ringed by successively older strata including the Bearpaw Formation. The formation is essentially flat-lying and because of its thickness (greater than 1000 feet) no complete section is exposed at any one locality. Crockford (1951) has given a composite section of the formation in this area but Lines (1947, in litt; 1963) gives the most complete description. The formation rests conformably upon the Lethbridge Coal Member of the Oldman Formation. The lower 755 feet of the Bearpaw Formation is termed the Manyberries Member and is divided into a number of subsidiary "zones" on weathering characteristics. It essentially consists, however, of dark shales with bentonites, tuffs and two fossil horizons; the lower yielding *Ostrea patina* Meek & Hayden and the upper yielding *Arctica ovata* (Meek

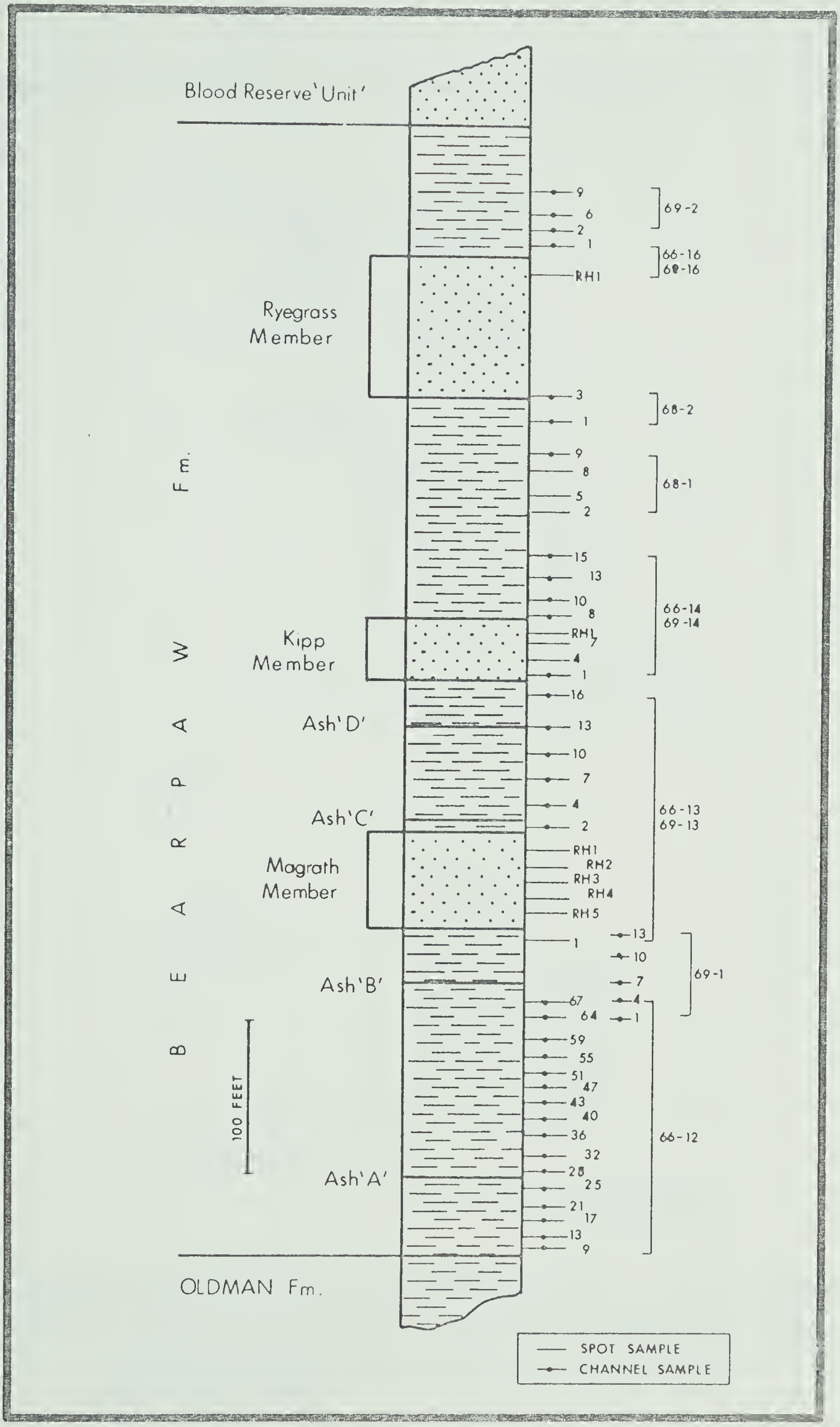

Figure 4: Composite stratigraphic section for the Bearpaw Formation of the Lethbridge area showing sample distribution and coding, (after Link & Childerhose 1931).

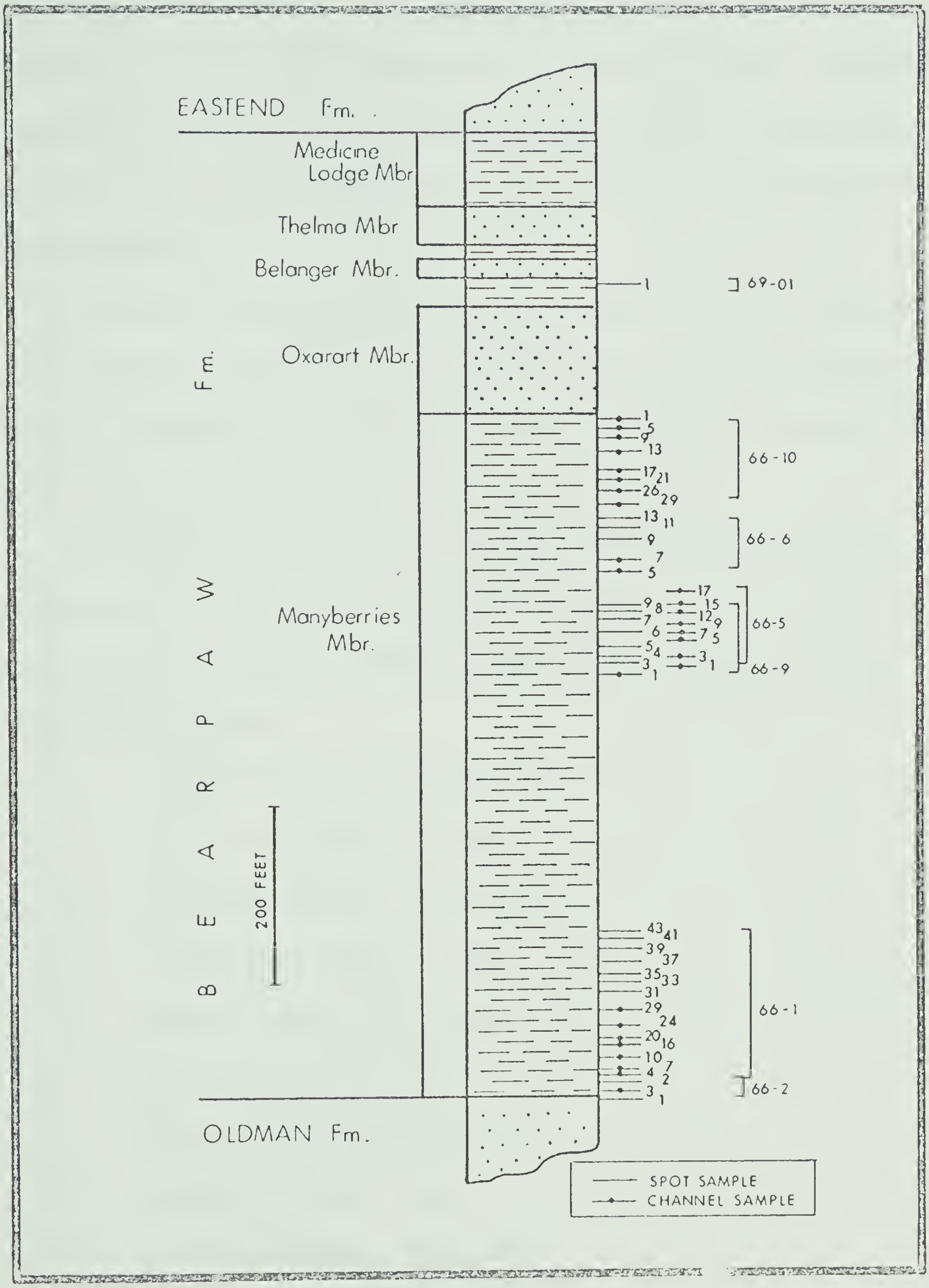

Figure 5: Composite stratigraphic section for the Bearpaw Formation of the Cypress Hills area showing sample distribution and coding, (after Lines 1963).

& Hayden). Above the Manyberries Member occurs the Oxarart Member of Furnival (1941), 110-130 feet of well bedded and well sorted, buff to yellow sandstone with some coaly horizons at the top. Succeeding this is the Belanger Member consisting of 75-95 feet of shale, siltstone and sandstone; the Thelma Member, 20-40 feet of well bedded massive yellow to buff sandstone; and the Medicine Lodge Member, 70 feet of dark, blocky shale. The Medicine Lodge Member is conformably overlain by the Eastend Formation.

The regional dip of the formation in this area is less than 10 degrees in an easterly direction, little faulting has occurred but there is much slumping and deep weathering. A composite section of the Bearpaw Formation in this area is illustrated in Figure 5 and a detailed location map is shown in Figure 3.

It is interesting to note, for the sake of comparison, that in the South Saskatchewan river valley area the Bearpaw Formation consists of alternating silt, clays and sands which Caldwell (1968) has divided into a number of members. These are, from top to bottom:-

1) Aquadell Member - silty clays.
2) Cruikshank Member - sands.
3) Snakebite Member - silty clays.
4) Ardkenneth Member - sands.
5) Beechy Member - silty clays.
6) Demaine Member - sands.
7) Sherrard Member - silty clays.
8) Matador Member - sands.
9) Broderick Member - silty clays.
10) Outlook Member - sands.
11) Unnamed Member - silty clays.

Regional Correlation

The position of the Bearpaw Formation with respect to western Canadian and

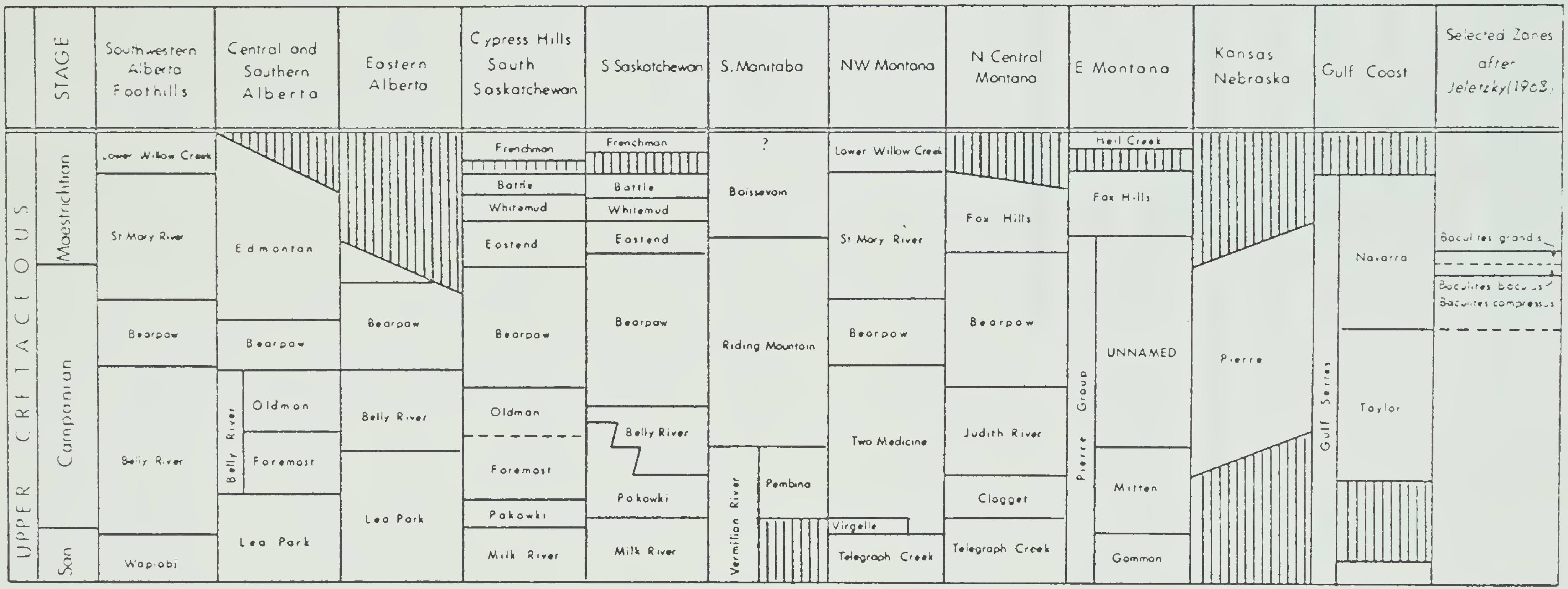

Figure 6: Correlation chart of selected sections of Upper Cretaceous strata in North America showing the position of the Bearpaw Formation, (after Cobban & Reeside 1952, Williams & Burk 1964, Jeletzky 1968, Caldwell 1968 and Given 1969).

American stratigraphy is illustrated in Figure 6. In terms of the reference sequence for the western interior of the United States the formation is correlative with the De Grey, Verendrye and Virgin Creek Members of the Pierre Formation. The Bearpaw Formation also correlates with the lower two-thirds of the Navarro Group and the upper part of the Taylor Group of the classic Gulf Coast section. It is also correlative with a part of the uppermost Chalk of the Isle of Wight section in England, the zone of Belemnitella mucronata (Rowe 1908) and to the upper Chalk exposed at Champagne, France - the type section for the Campanian Stage. The Campanian of the standard European sequence comprises the ammonite zones Diplacmoceras bidorsatum to Kossmaticeras theobaldianum.

CHAPTER III

RESEARCH TECHNIQUES

Methods of extracting palynomorphs from rock have been known for many years. Acid was first used in the extraction technique early in the twentieth century. Modern methods are well documented in Funkhouser & Evitt (1959), Brown (1960), Schopf (1964) and Gray (1965). It is good practice, however, for palynologists to give some account of their procedures so that colleagues may critically evaluate their data and conclusions. It is possible that a worker may unsuspectingly bias results by use of a particular technique or reagent, or leave samples open to laboratory contamination (Wilson 1964). The following method was used in extracting microplankton from samples of the Bearpaw Formation of southern Alberta.

1) Sampling

Extreme care was taken to avoid contamination from Recent material and "leaked" fossils. The Bearpaw Formation is often quite deeply weathered so that at least two feet of the formation must be removed from the outcrop before any samples can be taken. Both channel and spot samples were used. The distribution and type of sampling of the two sections are illustrated in Figures 4 and 5. The samples were taken at intervals of ten feet where possible. Care was exercised in keeping all sampling tools clean and in placing the samples in clean linen sampling bags.

All samples were numbered according to the following scheme:-

Example: JW69-13-2

JW - Collector, Dr. J.H.Wall.

69 - Year of collection

13 - Locality number.

2 - Sample number.

A brief description and the geographic location of the localities is documented in Appendix A. All the samples are stored at the Research Council of Alberta, Edmonton, Alberta, in the care of Dr. J. H. Wall.

2) Laboratory Procedures

Every sample was given individual treatment to ensure the best results. Periodic checking was carried out to see that processing was progressing satisfactorily and to determine the course of future treatment. All materials and apparatus were thoroughly cleaned before and after use.

Mechanical Disintegration

In many cases mechanical disintegration was achieved by allowing samples to stand immersed in distilled water for an hour. An iron pestle and mortar were used to disaggregate the more coherent samples. Contamination was avoided by the use of a filter paper lining. The samples were crushed to "pea" size and transferred to a 250 mls. polythene beaker.

Chemical Disintegration

All samples were treated with approximately 37% hydrochloric acid to remove any carbonates present. Calcium carbonate, if allowed to react with hydrofluoric acid, the next step in treatment, produces a gel-like precipitate of calcium fluoride which is difficult to remove. The samples were then washed twice with distilled water by decantation.

Commercial hydrofluoric acid of 52% strength was then added to digest the silicate minerals. Samples were normally allowed to react for between two and four days before being washed to neutrality.

A check was made at the end of this stage to determine which maceration procedure to use and to see if a heavy liquid separation was necessary. In some cases certain heavy minerals remain after the hydrofluoric acid treatment. This was not the case with the Bearpaw Formation samples; and many samples, especially those from

the Cypress Hills, needed no further treatment and could be washed, stained and mounted. The Lethbridge samples, however, required maceration in 71% nitric acid for periods ranging from 10 to 20 minutes. Maceration was closely controlled so that no palynomorphs were destroyed. The maceration technique directly dissolves and converts the organic material into humic acid. All samples needed, therefore, a further treatment of 10 to 20 minutes in 2% potassium hydroxide to remove the humic acid fraction.

Beyond the hydrofluoric acid stage all the samples were handled using the filtration system of Neves & Dale (1963). This system enables samples to be macerated, washed and stained without the transference of material from one receptacle to another. The apparatus consists of a 150 mls. Buchner funnel with a fritted glass filter of 10-15 microns pore size; a 1000 mls. filtering flask with a side tube and a two-way rubber bulb. The funnel is fitted to the flask and the sample is added together with copious amounts of distilled water. The sample is then filtered, removing all the fine organic material. The filtration equipment is cleaned with Schultze solution and distilled water after each sample run.

Once maceration and washing were complete the samples were lightly stained, using Safranin 0, and washed with distilled water. The stained residues were then stored with a drop of hydrochloric acid or phenol to prevent fungal growth, in small 15 mls. phials.

3) Mounting

A concentrated drop of the sample residue was added to a 5 mls. phial into which has been placed 4 drops of elvanol and 4 drops of distilled water. The solution was thoroughly mixed and then spread evenly on No. 1., 22x22 mms. cover slips and allowed to dry slowly under cover. The cover slips were then inverted and mounted on 3 x 1 inch, 0.96-1.06 mms. thick slides with canada balsam.

Elvanol is a polyvinyl alcohol which is purchased as a powder. It is made up

into a clear liquid by adding the powder to warm water. The use of elvanol ensures that the palynomorphs all lie in the same plane close to the cover slip and remain fixed in position. The use of canada balsam ensures the permanence of the slides but detracts from contrast in photographic work.

4) Examination

All samples were studied using Leitz Laborlux microscope 595949, (of the Department of Geology, University of Alberta), with the slide label to the right of the observer. Co-ordinates quoted in the text refer to the mechanical stage of this microscope; a reference co-ordinate for the upper left hand corner of the slide is also given on the slide labels, following the method of Pierce (1959).

One slide of each sample was studied for relative proportions of pollen, spores and microplankton. The reliability of the results was calculated using the chart of Van der Plas & Tobi (1965). Where the microplankton content was greater than 10% the first slide plus 2 additional slides of the same sample were examined in detail. A complete set of slides will be lodged with the Palynological Collections of the Department of Geology, University of Alberta.

5) Photomicrography

Specimens were photographed under Leitz Ortholux microscope 594209 (of the Department of Geology, University of Alberta), which is equipped with an Orthomat camera attachment. Adox KB 14 film was used throughout. The films were developed commercially but printed in the Department of Geology using Kodak Kodabromide F-4 photographic paper.

6) Repository

All holotypes, and other illustrated specimens of this study will be lodged in the Palynological Collections of the Research Council of Alberta, Edmonton, Alberta.

CHAPTER IV

RECENT PERIDINIALES - A SUMMARY REVIEW

Introduction

This work describes the organic walled microplankton of the Bearpaw Formation of southern Alberta; the term microplankton is used in the restricted sense to include only the acritarchs and dinoflagellates. It is feld that a better understanding of these organisms in the fossil record requires a sound knowledge of the modern representatives.

The acritarchs, by definition a fossil group containing algal-like organisms of doubtful affinity (Evitt 1963), are not known from the modern microplankton although there are a number of problematical planktonic organisms that are regarded by some as best treated as acritarchs (Sarjeant 1969). The dinoflagellates, in contrast, are an important part of the modern microplankton and are fully described below. Indeed Patton et al. (1967) show that Gonyaulax polyhedra Stein is nutritous and could possibly be harvested to supplement the world's food supply.

Dinoflagellates are contained in the plant division Pyrrhophyta Pascher 1914. The name is derived from the Greek pyrrhos - meaning flame coloured, red, yellowish-red or tawny, and phyta - meaning plants. The distinctive colouration of these organisms is due to the presence of the carotenoid pigments dinoxanthin and peridinin. The Pyrrhophyta are also characterised by the presence of chlorophylls a and c, the possession of two flagella, a large and prominent nucleus, a variable number of membrane bound pulsules (Morris 1967) or pusules (Fritsch 1935) and by distinctive sculpturing patterns on the cell surface (Morris 1967).

The division is divided into two classes - the Desmophyceae Fott 1959 and the Dinophyceae Pascher 1914. The former are characterised by a lack of plates on the cell wall, two anteriorly placed flagella, a single longitudinal groove that

divides the theca into two valves or an unequal division of the cell by an anteriorly developed transverse girdle. This class has little importance in the geological record although two Jurassic genera, <u>Nannoceratopsis</u> Deflandre 1938, Lower to Upper Jurassic, and <u>Palhistiodinia</u> Deflandre 1938, Upper Jurassic, have been placed within it.

The Dinophyceae are, however, important in the fossil record and have a recorded geological range from Silurian to Recent (Sarjeant 1967). All other fossil genera of the dinoflagellates, except those mentioned above, may be assigned to this class. The class includes free-living single celled forms to palmelloid, colonial, filamentous non-motile forms. Certain members are endoparasites, some ectoparasites and some symbionts. A description of these specialised forms may be found in Fritsch (1935). Members of the Dinophyceae occur in fresh, brackish and marine water and their feeding habits may be holophytic, holozoic or saprophytic and in certain forms a combination of habits is employed. The presence of a cellulosic cell wall and chlorophyll does, however, allow the placement of this group in the plant kingdom.

The palynologist is of necessity concerned with the marine and freshwater, free-living holophytic forms. The majority of these are placeable in one of two orders, the Gymnodiniales Lindemann 1928 and the Peridiniales (Schutt) Lindemann 1928. The major distinction between the two is the lack of a well defined cell wall in the Gymnodiniales; hence the name. An excellent account of the Gymnodiniales has been published by Norris (1966). Wall & Dale (1968a) have demonstrated that members of the Gymnodiniales are capable of producing several distinctive cyst morphotypes that resemble the acanthomorphitid and herkomorphitid acritarchs, but there is some doubt that these could be fossilised. It is of interest to note that Fritsch (1935) and Morris (1967) regard the Gymnodiniales as a "primitive" order. Fossil dinoflagellates are thought to belong to the Peridiniales, although this is not fully proven (Evitt 1961; Wall 1965; Wall & Dale 1968a).

Morphology of the Peridinialean Theca

The Peridiniales possess a three-layered cell wall (Loeblich 1969). The innermost layer, external to the cytoplasmic membrane is called the pellicle, it is unornamented and made up of fibrous cellulose; the second layer, called the theca, is composed of two to many separable plates, unornamented or ornamented, which are held together by a cementing substance and are also composed of fibrous cellulose; and a third layer of thecal membranes which surround the theca and attach along the thecal plate junctions. Loeblich & Loeblich (1966) in discussing cell wall composition quote the results of B. E. Volcani of the Scripps Institute of Oceanography who found 94% cellulose, minor lipids, minor proteins and inorganic matter.

Some members of the Peridiniales possess an internal structure called the internal skeleton, which consists of opaline silica. This has been observed in the fossil Actiniscus Ehrenberg ex Downie & Sarjeant 1964 (1965) and in the living state by Schutt (1891). The "skeleton" consists of four parts; two large, cupped, five rayed stars, and two smaller stars. It is uncertain, however, whether these forms should be included within the Peridiniales.

The peridinialean test, generally 20 to 150 microns in length, may be divided into an upper half, termed epitheca, and a lower half, termed hypotheca, by a transverse furrow. These areas are often subdivided by sutures, grooves or growth areas into thecal plates, for which Kofoid (1909) instituted a nomenclatural system. The epitheca carries two series of plates assignable to an apical series and a precingular series. The cingular plate series separates the epitheca from the hypotheca. The hypotheca, like the epitheca, carries two series of plates, the post-cingular and the antapical. Additional plates, if present, are termed anterior or posterior intercalary plates according to their position on the theca. A somewhat variable naming system is used for the sulcal plates (Kofoid op. cit., Balech 1959). Plates are numbered from the ventral area in a counterclockwise direction, when viewed from the ventral side.

The two flagella are inserted in two pores or a common pore in the sulcal area. One of the flagella is thread-like, arises from the posterior pore and lies along the longitudinal groove. The other flagellum is ribbon or band shaped, arises from the anterior pore and lies along the transverse furrow. Hall (1923, 1925) describes each flagellum as terminating at a basal granule. Each granule is connected by a rhizoplast to an extranuclear centrosome which lies adjacent to the nucleus. The only study of flagellar ultrastructure is that of Pitelka & Schooley (1955), who described that of <u>Gyrodinium</u> Kofoid & Swezy 1921, a member of the Gymnodiniales; although Dodge (1968b) does figure a longitudinal section of a dinoflagellate flagellum.

The peridinialean form varies from spherical, subspherical to peridinoid. Other forms may appear such as rectangular to polygonal and in some horns are developed; this is especially prominent in <u>Ceratium</u> Schrank <u>ex</u> Loeblich & Loeblich 1966.

The protoplasm commonly consists of an outer dense and granular region containing chloroplasts and an inner region containing the nucleus and pulsules. In the area of the flagellar pores the cytoplasm often becomes more fluid and readily forms pseudopodia. Chloroplasts are of variable form, but most commonly discoid and arranged peripherally in the cell; some species, however, have a single lobed chloroplast which is often accompanied by pyrenoids. Food is stored as starch in the pyrenoids or as discrete starch granules. Dodge (1968a) gives a full account of chloroplast structure.

The nucleus is a large prominent structure and of particular interest in that its chromosomes remain in the condensed state during interphase. Dodge (1963, 1964, 1966) and Leadbeater & Dodge (1967), describe the nuclear structure and division in members of the Dinophyceae.

Within the protoplasmic contents of the cell are certain structures called pulsules. These are commonly elongate or bilobed organs which open to the exterior by way of delicate canals. Some species carry two pulsules that are connected.

The pulsule canals often open to the exterior at one of the flagellar pores. The function of the structures is debatable (Fritsch 1935, Morris 1967). In addition an eyespot or ocellus may occur and in some species trichocysts are present. Dodge & Crawford (1969) discuss the fine structure of a member of the Gymnodiniales and also refer to other similar work. Figure 8 is a diagrammatic illustration of the peridinialean morphology.

Physiological Aspects of the Peridiniales

An account of certain physiological and biochemical processes and data for the Pyrrhophyta has been published by Loeblich (1966).

Photosynthetic and non-photosynthetic forms are capable of utilising mono- and disaccharides, fatty acids and amino acids for nutritional purposes. The photosynthetic forms can utilise nitrate, nitrite, ammonium salts in low concentrations, various amino acids, urea and uric acid as nitrogen sources. All members of the Peridiniales have one or more vitamin requirements; commonly vitamin B 12, less commonly thiamin and biotin.

Barker (1935) indicated a predominance of carbohydrate synthesis in the photosynthetic processes of Peridinium Ehrenberg 1832. Many workers have recently been concerned with the diurnal rhythms of photosynthetic rates, photosynthetic capacity and bioluminescence (Hastings 1959; Hastings et al. 1961; Sweeney 1960, 1964, 1965, 1969). The Peridiniales are very efficient at photosynthesis; the rate of respiration is approximately 10% of the maximum rate of photosynthesis and the respiratory and photosynthetic quotions are approximately at unity.

Reproduction in the Peridiniales is usually asexual by simple binary fission. The division of the theca usually takes place obliquely along the longitudinal axis with the line of fission passing through the point of insertion of the flagella such that one flagellum passes to each of the daughters. In many forms fission takes place

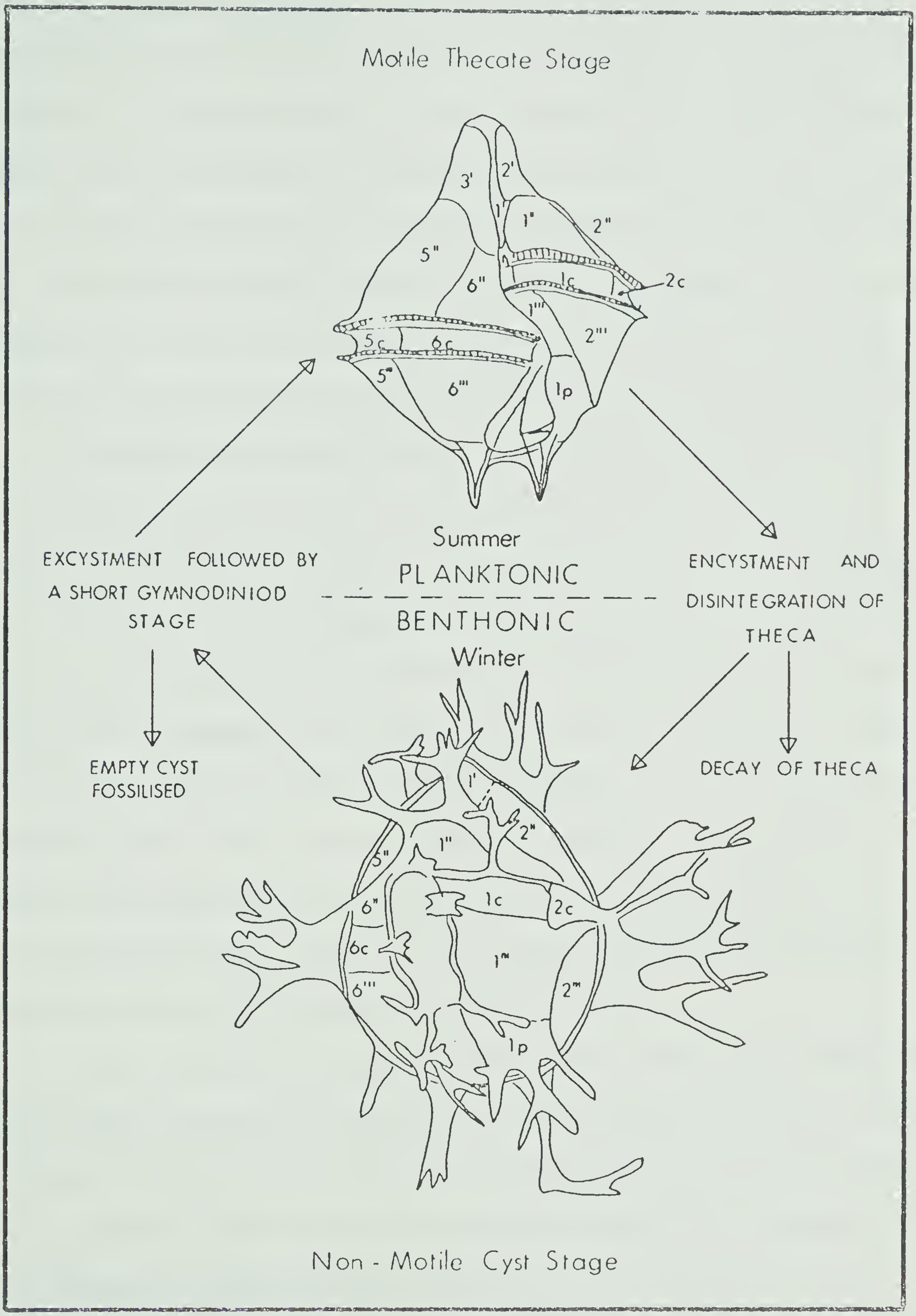

Figure 7: Diagrammatic representation of the peridinialean life cycle, (after Wall & Dale 1968a).

along predetermined thecal plate boundaries. The theca may be lost during asexual reproduction so that each daughter cell must regrow a new theca; in other cases half the theca is lost so that only half of the theca is regrown. In Ceratium there is sometimes an incomplete division so that a chain-like colony results. Initial daughter cells closely resemble the gymnodinialean dinoflagellate; this is taken by some as a possible indication of the "primitive" condition (Fritsch 1935, Morris 1967). Sousa e Silva (1969) described asexual reproduction in Goniodoma sp. as occurring by mitosis or as a result of direct division without the production of mitotic figures. Actual division occurs within the theca whilst the organism is in a sedentary stage.

The existence of sexual reproduction in the Peridiniales is doubted by some but it has been recorded by Zeder bauer (1904) and Entz (1909, 1924) and more recently by von Stosch (1964, 1965). In all cases this was in the genus Ceratium. Small individuals within the Ceratium population are the male gametes, the larger ones are the female gametes or vegetative cells. The females ingest the male gamete during sexual reproduction, the two gametes uniting to form the zygote. Morris (1967) described sexual reproduction, again in Ceratium, where a conjugation tube was employed and in which the gametes fused. Vegetative cells appear to be haploid, but the zygotes have not been observed to form a resting stage with a subsequent reduction division. It has, however, been suggested that dinoflagellate cysts are the resting stage, but this has not been proved.

The life cycle of the Peridiniales is described in Wall & Dale (1968a), and that of Pyrodinium bahamense Plate 1906 in Wall & Dale (1969). Figure 7 summarises details of the life cycle. Particularly interesting is the existence of a short lived "gymnodinoid" stage which is thin-walled and temporarily uniflagellate in the case of Gonyaulax digitalis (Pouchet) Kofoid and is avalvate in the case of Pyrodinium bahamense. Especially interesting in the process of excystment is the formation of the archeopyle. It is suspected that it forms due to an enzymatic dissolution along predetermined lines, usually closely related to suture lines (Evitt

& Wall 1968, Wall & Dale 1969). Ecdysis of Pyrodinium has also been described by Wall & Dale (1969), but the significance of this is as yet unclear.

Conditions of encystment are, imperfectly known. It may occur as a natural phase in the life history following a period of exponential growth, as a means for sexual reproduction, as protection against adverse conditions, or as a hibernation device (Wall & Dale 1970). A good discussion is given in Wall & Dale (op.cit.). The development of the cyst within the theca is also imperfectly known. Evitt & Wall (1968) described the process in Peridinium limbatum (Stokes) Lemmermann. Encysting cells are recognised by their dense cellular contents and lack of mobility. The endoblast (capsule) is secreted at a late stage of the encystment often after the formation of the outer wall; it is a primary structure and its proper development is necessary if the cyst is to survive. Norris & McAndrew (in press) have also described various developmental stages. These may in fact be inviable cysts and as such not typical. The cyst is an important part of the peridinialean study but it is generally neglected by modern algologists. It is preserved in the fossil record and will be fully described later.

Behavioral and Environmental Aspects of the Peridiniales

Members of the Peridiniales are noted for their bioluminescence; the light produced is blue-green and is produced as a result of a certain enzymatic reaction (Hastings & Sweeney 1957, Soli 1966 and Hastings & Bode 1961). The luminescence is of two types, either a rapid flashing or a steady dim glow; the former produced as the result of an external stimulus. Kelly (1968) described bioluminescence at Woods Hole, Massachusetts and concluded that the dinoflagellates are responsible for most near surface bioluminescence. It was also suggested that bioluminescent forms are derived from a common ancestor.

Locomotion is achieved by beating the flagella in the manner described

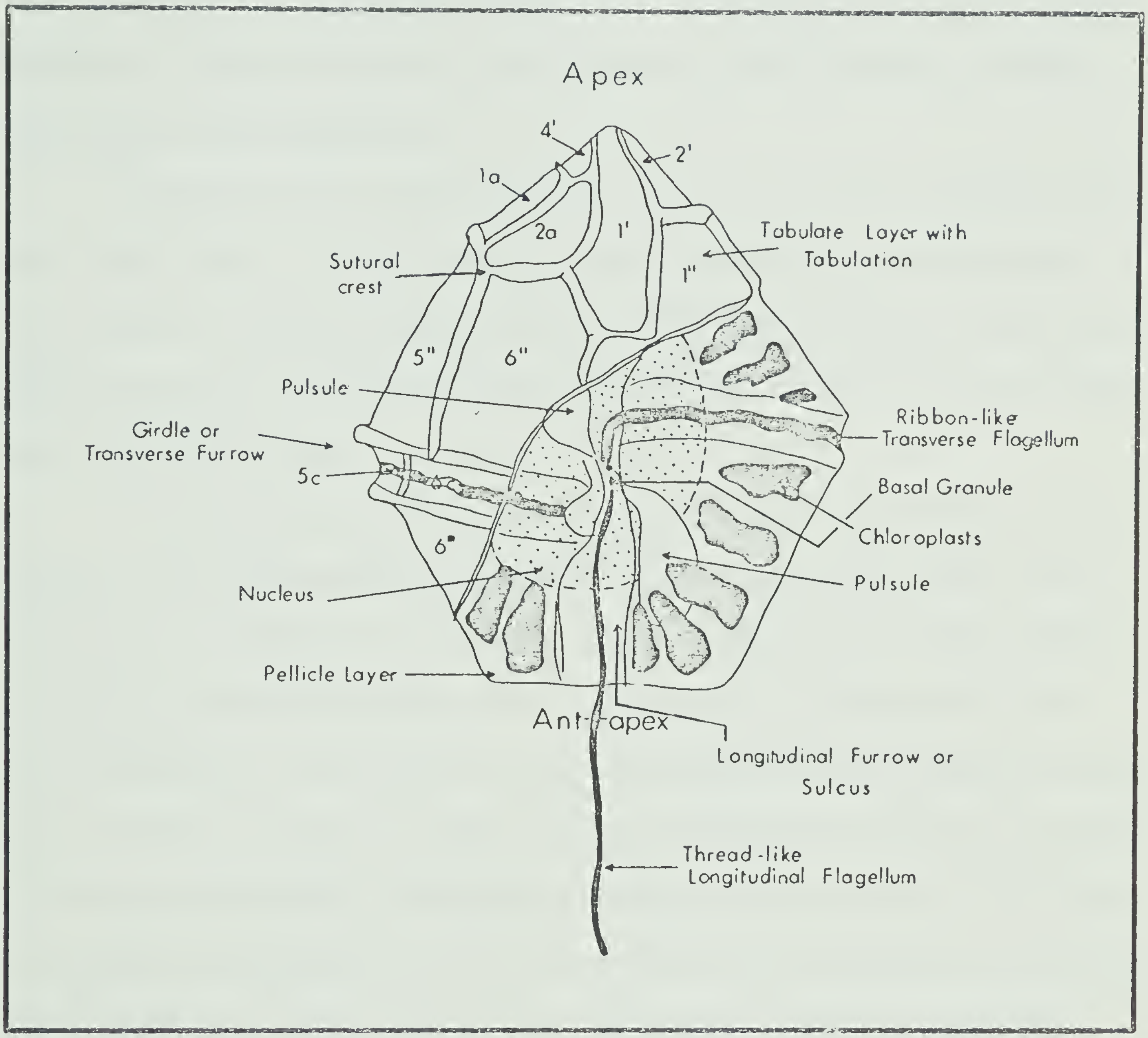

Figure 8: Diagrammatic representation of the external and internal morphology of a typical member of the Peridiniales.

previously, but it is of interest that the transverse flagellum also contributes a forward drive to that generated by the longitudinal flagellum. The organism moves through the water in a spiral manner, apex first (Jahn et al. 1963). A maximum mean velocity of 1 metre per hour has been achieved at 3% salinity and at 24°C (Hand et al. 1965).

Phototaxis is a variable feature in the Peridiniales and it may be negative or positive. This ability leads to a concentration of cells in optimum conditions and diurnal vertical migrations.

The products of excretion passed out into the surrounding fluid often contain various toxins. A recent account of a dinoflagellate bloom and subsequent toxin production has been reported by Wood (1968), Robinson (1968), Coulson et al. (1968), Adams et al. (1968) and Ingham et al. (1968). Glycolic acid is the normal major product of excretion.

The Peridiniales are an important part of the total microplankton and are primarily controlled in vertical and areal distribution by salinity, light intensity, temperature and nutritional requirements. Loeblich (1966) quotes a figure of 2% as being the optimum salinity for certain marine species, well below that of the open sea (3.5%), and the ability to adapt to a sudden decrease in salinity is greater than the ability to adapt to a sudden increase as suggested by studies of one species of tide pool dinoflagellate. Temperature toleration limits are from 1° to 35°C but the optimum lies between 18° and 25°C according to the species under consideration. Muller (1959) quotes 20°C as the optimum temperature. Marine photosynthetic forms can tolerate very high light intensities and Vozzhennikova (1965) states that the Peridiniales are confined to the top 50 metres of the oceanic photic zone; the major concentration being within 5 to 40 metres depth. Kiselev (1950) found that the position of the densest concentration of dinoflagellates was a function of light intensity such that in continuous solar illumination it is placed at 10 to 15 metres depth and, under prolonged cloud cover, at the surface.

Classification of the Peridiniales

The Peridiniales have in the past been variously classified as botanical and zoological entities and the present classification has evolved with the work of such people as Pascher (1914, 1931), Lindemann (1928), Schiller (1937), Fritsch (1935), Graham (1951), Chatton (1952), and Kiselev (1954). A modern classification, based exclusively on the thecate stage, is given below after Fritsch (op. cit.) and Morris (1967). The classification has remained stable since about 1930 except for such differences of opinions as to whether the Dinophyceae, for instance, should be regarded as a sub-division or as a class.

Division PYRRHOPHYTA Pascher 1914

Class DESMOPHYCEAE Fott 1959

Order Desmomonadales Pascher 1914 - naked, longitudinal divided forms.

Order Thecatales Lindemann 1928 - armoured, longitudinal divided forms with apical tooth.

Order Dinophysiales Lindemann 1928 - armoured, transversely divided by anteriorly placed girdle.

Class DINOPHYCEAE Pascher 1914

Order Gymnodiniales Lindemann 1928 - unarmoured dinoflagellates, acritarchs ?

Order Peridiniales (Schutt) Lindemann 1928 - armoured dinoflagellates.

Order Rhizodiniales Pascher 1931 - amoeboid forms.

Order Dinocapsales Pascher 1931 - palmelloid forms.

Order Dinococcales Pascher 1931 - coccoid forms.

Order Dinotrichales Pascher 1931 - filamentous forms.

Wood (1954) is of the opinion that the genus concept in the Linnean sense can have no significance in dinoflagellate taxonomy because of the paucity of sexual reproduction, this view is also held by certain palynologists (Cox pers. comm.). Bursa (1963) described certain morphogenetic factors that give rise to aberrant dinoflagellates, which have been described as separate species by some workers. There is a possibility such aberrant fossil cysts also occur.

CHAPTER V

MORPHOLOGY AND CLASSIFICATION OF FOSSIL MICROPLANKTON

That part of the life cycle of modern dinoflagellates (Peridiniales) preserved in the fossil record is generally believed to be the cyst (Evitt & Wall 1968, Wall & Dale 1968a). There is no positive evidence that the motile theca can also be preserved. In addition it is likely that acritarchs are the cysts of planktonic organisms, possibly of the Gymnodiniales as discussed earlier. Consequently the following account is entirely concerned with the cyst stage of the Peridiniales and acritarch producing organism.

Dinoflagellates

Morphology and Composition

In overall shape most members of the Peridiniales can be described as spherical, ovoidal, peridinoid, rhomboidal or pentagonal. Modern forms are somewhat flattened dorsoventrally; a property which is accentuated on fossilisation. Morphological terms useful in describing dinoflagellate cysts have recently appeared in Downie & Sarjeant (1966), Sarjeant (1969), and Evitt (1969) and a glossary of terms is at present being compiled by Sarjeant & Williams (Sarjeant pers. comm.).

Dinoflagellate cysts are made up of resistant walls, mineralised in some rare forms, composed of an acid-insoluble organic substance. Wall & Dale (1968b) described mineralised cysts with a two layered wall structure. The outer mineralised layer is composed of calcite (aragonite?) in radial or microgranular habit. The inner layer is of an organic composition. A totally organic cyst wall is found in the majority of the Peridiniales. Staplin (1969b) and Van Gijzel (1967a, 1967b) have demonstrated that the composition of the cyst wall of dinoflagellates is not the same as the walls of pollen and spores. Kjellstrom (1968) recognised the presence of C00H,

CH2, and CH3 groups, carboxylic groups and long chain alifatic saturated carbohydrates in the walls of leiospheres. It is clear that much more research is needed.

Cysts are typically two layered, being composed of an outer periphragm and an inner endophragm. The periphragm is often solely responsible for the construction of the processes. Norris & McAndrew (in press) have introduced the terms pericorpus and endocorpus to refer to the discrete bodies formed by these respective layers. Evitt (1969) uses the terms periblast and endoblast. He regards the terms of Norris & McAndrew as being poorly formulated in that the words are constructed from Latin and Greek roots (Evitt pers. comm.). The endoblast surrounds a central cavity called the endocoel. Jux (1968a, 1968b), in recent electron microscope studies of the walls of Hystrichosphaera bentori Rossignol 1961 and Cordosphaeridium inodes (Klumpp 1953), has revealed the two layers, similar in overall structure but differing in the frequency of small vesicles that were conspicuously present within the wall layers.

Three layered cysts are also known. The third layer either develops between the endophragm and periphragm and is called the mesophragm (Evitt 1969) or it develops outside the periphragm, in which case it is termed the ectophram. In some forms a single layered cyst wall is present; the single layer is most often the endophragm, but where this is not demonstrable the term autophragm is to be preferred (Evitt 1969).

In adhering to these rather strict terms homologous relationships are implied. This should be avoided as homology in dinoflagellate cyst walls has only been adduced between Peridinium limbatum and Deflandrea spp. by Evitt & Wall (1968). Caution is therefore advisable in the use of these terms.

The cyst is usually divided into two halves by the cingulum, which takes the form of a laevo-rotatory spiral in most cases, into an upper half, the epitract and a lower half, the hypotract. The surface of the test may be ornamented by granules, punctae, vermiculae, a reticulation or it may be smooth. Figure 9

illustrates the gross morphology of a dinoflagellate cyst.

Three main morphological cyst types are recognised; proximate, chorate and cavate. Proximate cysts are thought to exhibit the same general form as the parent motile theca, with cingulum, sulcus and tabulation. Cyst tabulation is described and labelled in much the same way as for the motile theca, and is likewise variable. The wall layers are usually in contact, but small pericoels (cavities developed between the periphragm and endophragm) are sometimes present beneath processes and horns.

Chorate cysts are characterised by processes, often reflecting the original tabulation of the parent theca. The processes may be intertabular (gonal or sutural), intratabular or non-tabular. This kind of cyst is also characterised by a 0.5 - 0.6 condensation ratio, derived from the following expression:-

$$\frac{\text{Radius of endocoel}}{\text{Overall radius}}$$

There is also a proximo-chorate subgroup that is transitional between the two groups discussed above. These typically have a 0.6 - 0.8 condensation ratio, carry a tabulation and also possess processes, usually of the intertabular type.

The third major group, cavate cysts, are readily distinguished by their possession of large pericoels. The endophragm and periphragm are typically not in contact except along an equatorial zone, in which case the cyst is termed bicavate or at the apex and antapex in which case the cyst is termed pterocavate. Figure 10 together with Figure 9 illustrate the three main types of dinoflagellate cysts.

Since 1960 cyst types have been tied to a functional definition, the condensation ratio (an expression of the position of cyst formation within the parent theca). Proximate cysts form just below the cell wall of the parent theca whereas chorate cysts condense and form well within the parent cell. In an attempt to morphologically describe these various cysts an objective descriptive terminology must be used without the implication of any functional purposes. Cavate cysts, for instance,

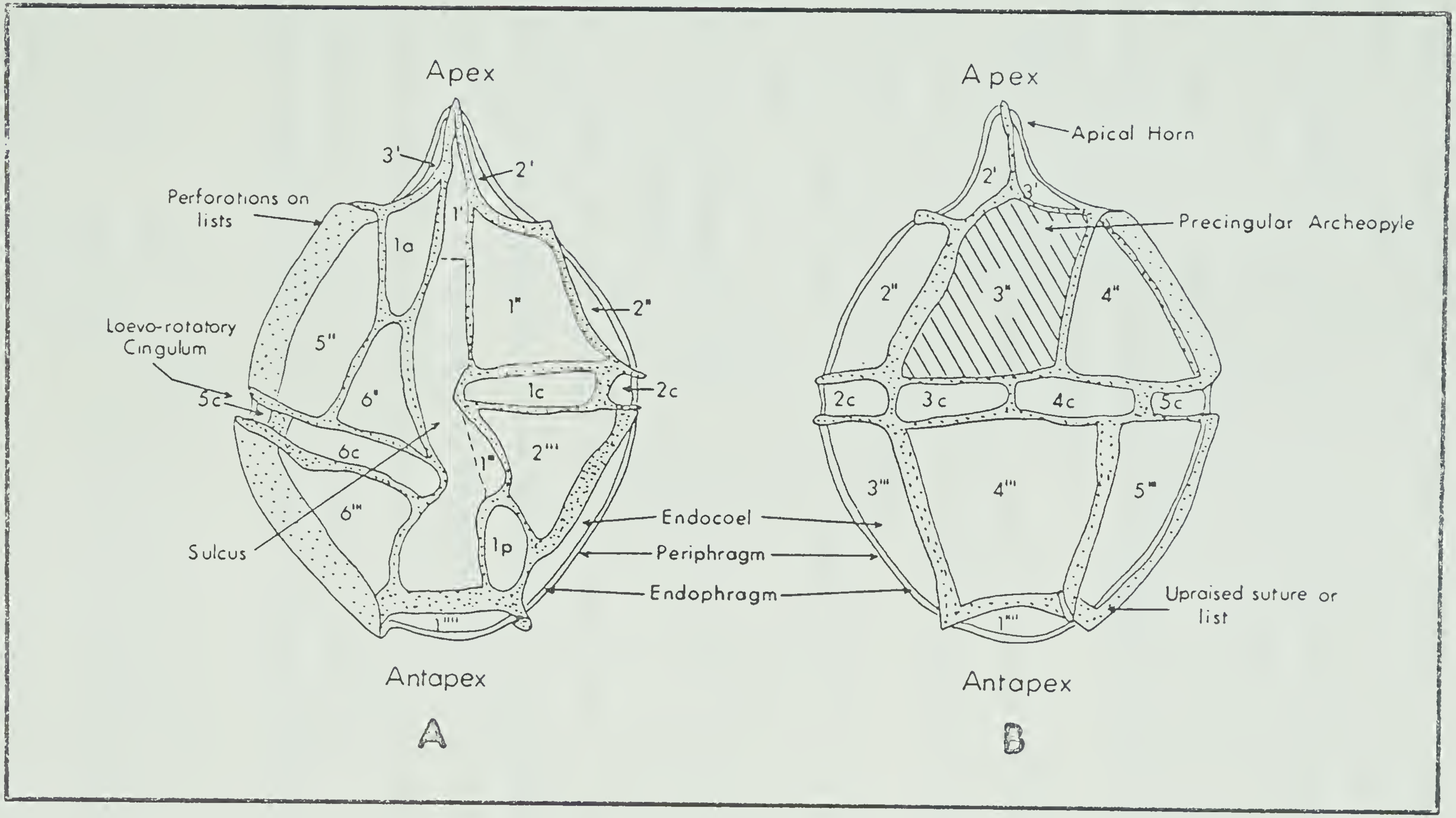

Figure 9: External morphology of a typical proximate dinoflagellate cyst with a precingular archeopyle. A - Ventral view B - Dorsal view. 1'-3', apical plates; 1a, anterior intercalary plate; 1" - 6", precingular plates; 1c-6c, cingular plates; 1'''-6''', post cingular plates; 1p, posterior intercalary plate; 1'''', antapical plate, (after Sarjeant 1967a).

could be termed proximate in a functional sense as some forms carry a tabulation, indicative of cyst formation in juxtaposition to the parent cell wall.

In the literature there is some confusion over the terms "spine" and "process", as pointed out by Harland (in press). In the present work the term spine will be avoided. All projections arising from the cyst will be termed processes and fully described using the terminology of Downie & Sarjeant (1966) and Sarjeant (1969). In this way there will be no functional implications. Processes may in fact be regarded as merely a form of "ornamentation", may support the cyst within the parent theca or may be used to facilitate flotation.

The term horn is applied here to a major extension of the cyst body, which may carry portions of the tabulation (see Evitt 1969). This term must also be used with care so that it is not confused with process.

A major morphological feature of dinoflagellate cysts is the archeopyle (Evitt 1961, 1967). This is the opening in the cyst wall through which the organism escaped during excystment (Wall 1965). In most fossil forms this opening is conspicuous. The archeopyle is usually equivalent to one or more reflected plates of the thecal tabulation. It may develop within a reflected plate as a reduced archeopyle or it may include parts of surrounding plates as an enlarged archeopyle. Cavate cysts may possess an archeopyle in the periblast and/or the endoblast. That portion of the cyst which is lost or swings free of the archeopyle is called the operculum. Free opercula are often seen in palynological preparations. Evitt (1967) discussed the archeopyle extensively and erected a scheme to designate the various types:-

1) Apical - involving loss of apical plates; $\overline{A}$, Aa.
2) Intercalary - involving loss of intercalary plates; I, 2I, 3I.
3) Precingular - involving loss of precingular plates; P, 2P, 3P, 6P.

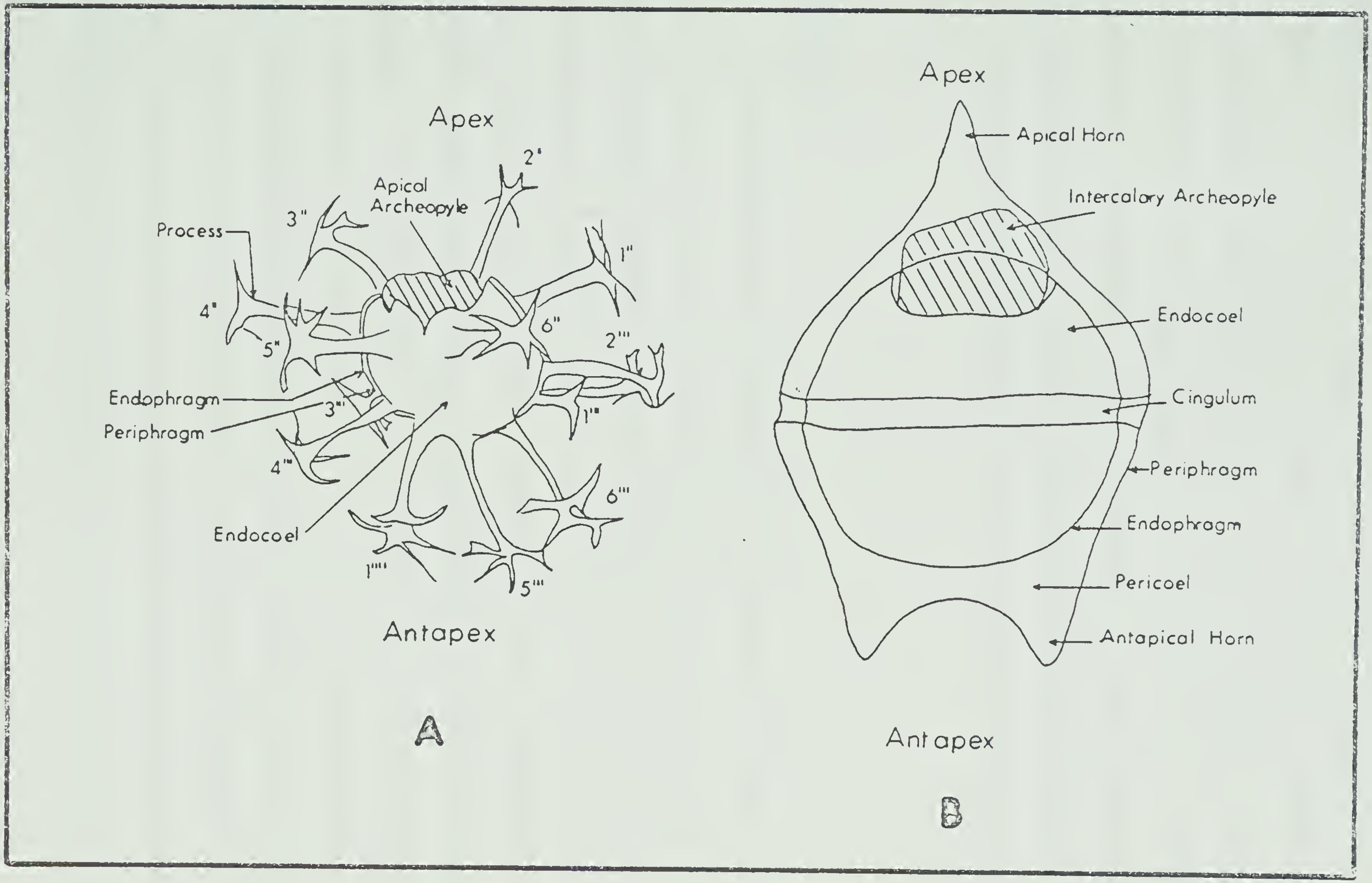

Figure 10: A–External morphology of a typical chorate dinoflagellate cyst with an apical archeopyle, (after Davey & Williams 1966). B– External morphology of a typical cavate dinoflagellate cyst with an intercalary archeopyle, (after Sargeant 1967a).

4) Combination - involving loss of plates from more than one plate series; $\overline{A}I$, $\overline{A}+P$, 2A + 6P.

The epithecal or epitractal archeopyle of Norris (1965) is included in the combination type. Other forms of archeopyle termed $\overline{AIP}$ a + 2Pa, Aa+3I and $\overline{AIP}$ have been described from freshwater dinoflagellate cysts by Norris & McAndrew (in press). Harland (in press) noted further archeopyle types, also of non-marine cysts, including one type tentatively designated CS. Norris & McAndrew (in press) suggest the possibility that archeopyle type might be useful in separating marine from freshwater forms. In any description of dinoflagellate cysts a full account of archeopyle structure is essential.

Classification

The classification of dinoflagellate cysts has passed through a number of phases. At first it was usual not to classify dinoflagellates beyond generic level. They were regarded as animals or plants according to a writers particular view; either being placed in the Class Dinoflagellata or the Class Dinophyceae respectively. Eisenack (1961), for instance, erected a zoological scheme, although he claims that from 1938 he regarded them as algae (Eisenack 1963a). In 1961 it was suggested by Downie *et al*. that dinoflagellates should be treated as plants under the International Code of Botanical Nomenclature (I.C.B.N.). This is the practice today. A similar system was employed by Vozzhennikova (1965, 1967) with a mixture of fossil and modern genera being placed into families. An important consideration in Vozzhennikova's scheme is that cavate cysts are fundamentally different from other cyst types. A separate subclass, the Endoflagellatophycidae, was erected to accommodate cavate types.

Sarjeant & Downie (1966) reviewed the situation as it stood then and erected a purely morphological classification for fossil dinoflagellates to exist alongside and independantly of the natural classifications of the thecate stage. The form-

generic concept was used and because such genera cannot be grouped into natural families (Article 3, I.C.B.N.) a number of artificial cyst-families were erected. Morphological parameters used in the scheme were overall form, shape, archeopyle formation and tabulation. It was pointed out that the relative importance of these parameters varied according to the cyst group under consideration. It is unfortunate that in using overall form i.e. proximate, chorate and cavate groupings, a growth hypothesis is implied which leads into certain difficulties; in particular that a cavate cyst (morphological) can be considered to be proximate if the growth hypothesis is accepted. These terms, in the author's opinion, must be used in their morphological sense only, as the processes of cyst formation are, as yet, largely unknown. Harland (1969) draws attention to the presence of morphologically transitional specimens between certain genera and species, an added difficulty in the scheme of Sarjeant & Downie (1966).

A subsequent approach is that of Mädler (1967) who placed fossil dinoflagellates into a new division: the Hystrichophyta, called a class by Mädler, of the plant kingdom. This division includes the Order Hystrichosphaerales Mädler 1963 which in turn includes the Family Hystrichosphaeraceae (O. Wetzel 1933) Mädler 1963, (Mädler's designation). It is obvious that the true nature of the "hystrichospheres" is ignored or unknown to Mädler.

Wall & Dale (1968a) suggested the erection of a comprehensive taxonomic approach to unite the fossil and modern dinoflagellates in a "natural" classification. Tabulation and archeopyle formation were regarded as the only taxonomically stable morphological characters. The scheme of Sarjeant & Downie (1966) was criticised on three main grounds: 1) two phases of the dinoflagellate life cycle could be assigned to different taxa at generic and family level; 2) too much emphasis was placed on the growth hypothesis, and 3) the classification effectively and unnaturally divides modern from fossil representatives. Wall & Dale (1968a) suggested that taxa should be formulated with reference to all phases of the organism's life history;

that if a taxon is erected on only one stage of the life cycle, then it can only be treated as a natural taxon if a population is studied; that one valid name be used, preferably the name of the extant organism; and that extinct taxa must be defined on morphological features having the greatest taxonomic potential. Certain taxonomic emendations would be required; modern taxa should be redefined to attribute some importance to the cyst stage of the life cycle; fossil and living synonymous dinoflagellates should adopt a single epithet. Extinct forms should be allocated to taxa at the family level on tabulation patterns, and to taxa at the generic level on tabulation, archeopyle formation and the nature of the ornamentation.

Norris & McAndrew (in press) favour separate classifications for the cyst and thecate stages. They criticise Wall & Dall (1968a) for not indicating how a natural population of fossil dinoflagellate cysts can be recognised. They also point out that there will be an accummulation of cyst types unassignable to natural thecate stages; and that the relative taxonomic importance of the growth hypothesis is not fully known. They question the taxonomic stability of archeopyle formation because certain freshwater cysts they studied had unique archeopyles but were quite clearly of Peridinium affinity. This is also supported by the work of the present author (Harland & Sarjeant in press, Harland in press). Norris & McAndrew (in press) recognise the importance of operational taxonomic units; that there is a need to organise data into conceptually meaningful units which can later be reorganised, synthesised and placed into biologically significant groups for a phylogenetic interpretation.

In offering a compromise between the comprehensive scheme of Wall & Dale (1968a) and the purely morphological scheme of Sarjeant & Downie (1966) Harland (in press) suggested that Quaternary dinoflagellates be dealt with under a "natural" comprehensive classification as suggested by Wall & Dale (op. cit.). It seems likely that all Quaternary fossil dinoflagellate cysts will be finally assigned to their parent thecae, in much the same way as Quaternary pollen and spores are

assigned to their parent plants. All pre-Quaternary dinoflagellate cysts would be classified on morphological grounds alone, but with their natural affinities stated where known or reasonably assured. In this way it will still be possible to erect probably dinoflagellate lineages, as Wall & Dale (1969) have done for Pyrodinium bahamense Plate 1906.

If the taxonomic hierarchy of Wall & Dale (1968a) is applied to fossil dinoflagellates two natural families and two artificial families would be recognised; the Gonyaulacaceae having a tabulation of 3-6', 6'', 6c, 6''', 1'''', the Peridiniaceae with a tabulation of 4', 7'', 4c, 5''', 2'''', plus anterior intercalary plates, a family to include all those fossil cysts that do not carry a tabulation and a family for forms with a tabulation not assignable to either Gonyaulacaceae or Peridiniaceae. Subfamilies could then be erected on archeopyle formation and genera erected on overall form, ornamentation, etc. It would, however, be premature to attempt such a scheme. In this work, therefore, the writer will use the system of Sarjeant & Downie (op. cit.), but will attempt to relate the described cysts to possible modern representatives or postulated lineages.

Acritarchs

The acritarchs constitute an artificial group of microfossils defined by Evitt (1963). Basically it includes "hystrichospheres" that lack features indicative of a dinoflagellate affinity. Their geological range is Precambrian to Holocene. Acritarchs are wholly aquatic and typically marine, although non-marine forms have been described (Churchill & Sarjeant 1963, Sarjeant & Strachan 1968, and Harland & Sarjeant in press).

Morphology

Excellent reviews of acritarch morphology are given by Sarjeant (1969) and Evitt (1969). They are characterised by a central cavity enclosed in an organic wall

which may consist of one or two layers. These layers may be in close contact or may be separated forming an inner body. The wall layers are variously ornamented. Kjellstrom (1968), and as discussed earlier, described various biochemical groups present in the acritarch wall. Medd (1966) described the fine structure of some Lower Triassic acritarchs using the electron microscope and demonstrated the taxonomic potential of this approach.

The test shape is variable but generally falls into the following categories: spherical, ovoidal, ellipsoidal, crescentic, prismatic, polygonal, or discoidal.

Many forms possess processes which either connect to the interior of the central body or arise only from the outer test layer. The processes may be solid or hollow. Cramer & Diez (1968) suggested the use of objective terminology in acanthomorphitid acritarch descriptions founded on discontinuously variable, independent and qualitative characters. The processes may be placed at random e.g. Baltisphaeridium (Eisenack) Downie & Sarjeant 1963 or they may be restricted to certain areas e.g. Acanthodiacrodium (Timofeyev) Deflandre & Deflandre-Rigaud 1961.

The test walls may be intact or perforated by a pylome which may be a regular circular opening, a slit, an irregular tear, a crescentic opening or a flap-like opening. Acritarch pylomes are described in detail by Loeblich & Tappan (1969).

Classification

Acritarchs are handled under the I.C.B.N. as form genera. Above generic level a non-Linnean system of classification is employed; the acritarchs being regarded as an incertae sedis group, Acritarcha Evitt 1963. The group is subdivided on morphology into subgroups e.g. Acanthomorphitae. The classification is described by Downie et al.(1963). Since the original publication, one subgroup, the Stephanomorphitae, has been removed and two additional subgroups, the Scutellomorphitae Brito 1967 and the Schizomorphitae Segroves 1967, have been added.

Recently a number of publications have appeared either modifying the scheme

of Downie et al. (op. cit.) or proposing an entirely different one. Deflandre & Deflandre (1964) accepted the scheme but preferred to treat the acritarchs as belonging to a paraorder subdivided into parafamilies. Staplin et al. (1965) reviewed the status of the leiospheres and acritarchous hystrichospheres. They amended existing diagnoses and erected new taxa using detailed structural criteria rather than gross morphology. They are of the opinion that a particular generic name should be reflected in the subgroup name to exemplify the particular morphology of that subgroup. In their systematics, therefore, they restricted the subgroup Acanthomorphitae and proposed two new subgroups, the Baltisphaeritae and Tasmanitae. Timofeyev (1965) proposed a new system of morphological groupings. The ancient phytoplankton i.e. those of the early Palaeozoic, were placed into such groups as the Spheromorphyda and Asteromorphyda which are then further subdivided into subgroups. The Spheromorphyda, for instance, is divided into the Monosphaeritae and Polysphaeritae.

In the present work the system of Downie et al. (1963) will be used, but with particular attention being given to structural features such as process and wall structure.

CHAPTER VI

SYSTEMATICS

Introduction

In this systematic treatment of the dinoflagellate cysts and acritarchs recovered from the Bearpaw Formation of southern Alberta a full description is given for each of the taxa encountered to facilitate comparison with taxa of other assemblages. Selected synonymies, giving reference to the original description, plates and figures and to important name changes, are given for the established species.

The classification of Sarjeant and Downie (1966) is employed for the dinoflagellate cysts but the natural affinities of the cysts are given where known or reasonably assured. New species and genera are described only where the author feels there are sufficient numbers of specimens to indicate the range of specific variability and/or, where the morphology is particularly unique.

The acritarchs are treated under the classification of Downie et al.(1963) but the approach of Staplin et al. (1965) is indicated where applicable. The author feels that since acritarch taxonomy is in such a state of flux it would be unwise to erect further new taxa. Species encountered are, therefore, informally designated.

The abbreviations O.D. and S.D. are used to indicate original and subsequent designation. In the dimension sections the figure in parenthesis is the arithmetic mean of the measured morphological parameters. The geological ranges given for the species and genera is after Sarjeant (1967b) unless otherwise stated. All the taxa described are from the Lethbridge and Cypress Hills areas. The reader is referred to Appendix A for the locality key and to Figures 4 and 5 for the stratigraphic positions of the samples.

PLANT KINGDOM

Division Pyrrhophyta Pascher 1914

Class Dinophyceae Pascher 1914

Order Peridiniales (Schutt) Lindemann 1928

Cyst-Family Gonyaulacystaceae Sarjeant & Downie 1966

Remarks

Davey (1969b) has recently emended this cyst family to include cysts produced by species of the family Gonyaulacaceae Lindemann, in much the same way as was suggested earlier in this thesis, on the basis of tabulation. He does not, however, include the cyst-family Microdiniaceae Eisenack emend. Sarjeant & Downie which Wall & Dale (1968a) clearly regard as having gonyaulacacean affinities. Until a full revision is attempted the original system is preferred.

Genus Cribroperidinium Neale & Sarjeant emend.
Davey 1969

Type Species: Cribroperidinium sepimentum Neale & Sarjeant 1963; O.D.

Remarks

Davey (1969) emended this genus to draw attention to the fact that the anterior intercalary series and the posterior circle series of plates, a group of plates at the antapex of the cyst but not regarded as being part of the antapical plate series, are not always clear. It is also important to note that the identification of this genus also seems to include recognition of the presence of additional

intratabular crests on any single reflected plate of the tabulation. The genus has a recorded geological range of Hauterivian-Lower Turonian.

Cribroperidinium sp.

Plate I., Figure 2.

Description

Proximate cyst, ovoidal in shape, the epitract is conical, the hypotract is hemispheroidal. The cyst is made up of periphragm and endophragm closely adpressed. The endophragm is up to two microns in thickness. The cyst is conspicuously granulate. A tabulation is present but difficult to decipher because of the number of the additional intratabular crests, and because the single specimen encountered was slightly broken. A cingulum, four microns wide is present and is also delimited by raised sutures, that are up to three microns high; much higher than the intertabular crests. The large archeopyle is precingular of the P type.

Figured Material

JW66-I-39(2) at 100.6-37.8; Bearpaw Formation, southern Alberta.

Dimensions

Length 85.0 microns, breadth 67.0 microns. One specimen was measured, the number of specimens studied.

Remarks

This specimen differs from other species of this genus in lacking a distinct apical horn, possibly because of breakage, and in carrying a markedly granulate "ornamentation". The single specimen encountered should not be relied upon in extending the geological range of this genus.

Affinities

This genus, possessing a Gonyaulacysta-type tabulation, has gonyaulacacean affinities with the gonyaulacoid lineage. Definite affinities have not been demonstrated.

Cyst-Family Pareodiniaceae Gocht emend. Sarjeant & Downie 1966

Genus Pareodinia Deflandre 1947

Type Species: *Pareodinia ceratophora* Deflandre 1947; O.D.

Remarks

This genus is characterised by a lack of tabulation, the presence of a single apical horn, and a 2I archeopyle. It has a recorded geological range of Bajocian-Albian.

Pareodinia sp.

Plate I., Figure II.

Description

Proximate cyst, elongate ovoidal in shape, composed of autophragm. Test granulate. The epitract is drawn into a long apical horn, which is distally oblate. Hypotract hemispheroidal. Tabulation is lacking. Archeopyle was not observed.

Figured Material

JW66-1-24(1) at 105.0-41.7; Bearpaw Formation, southern Alberta.

Dimensions

Length 40.0 microns, breadth 25.0 microns. One specimen was measured, the number of specimens studied.

Remarks

This form is small in comparison to other similar species of this genus. It also differs in having an oblate distal extremity to the apical horn, unlike *P. aphelia* Cookson & Eisenack 1958 which is evexate and *P. ceratophora* Deflandre 1947 which is acuminate. The single specimen encountered is insufficient evidence

to extend the geological range of this genus.

Affinities

Wall & Dale (1968a) consider this genus to have peridiniacean affinities with the pseudoceratoid lineage. No definite affinities have been demonstrated.

Genus Apteodinium Eisenack 1958

Type species: Apteodinium granulatum Eisenack 1958; O.D.

Remarks

This genus had a geological range of Valanginian-Cenomanian, but recently Gocht (1969) recorded a single specimen from the Upper Eocene of Germany. This genus is very similar in gross morphology to that of Pareodinia Deflandre 1947 but Pareodinia has a 2I archeopyle as opposed to the P type of Apteodinium.

Apteodinium sp. A

Plate I., Figure 3.

Description

Proximate cyst with a single observable wall layer carrying a patchy microgranulation. In plan the cyst appears reticulate. The cyst is ovoidal but carries a very prominent apical horn which has a squarish indented distal extremity. The tabulation is not visible except for the presence of a faint narrow planar cingulum, which is delimited by an alignment of the positive elements of the reticulation. The archeopyle is precingular formed by the loss of a single large precingular plate 3" ?, and is therefore of the P type.

Figured Material

JW66-5-7(2) at 104.0-40.6; Bearpaw Formation, southern Alberta.

Dimensions

Length 98.0(112.5)127.0 microns; breadth 98.0(99.0)100.0 microns. Two

specimens were measured, the number of specimens studied.

Remarks

These specimens compare quite favourably with A. maculatum Eisenack & Cookson 1960, except in the possession of a large prominent apical horn and in the style of "ornamentation", and with A. tamboviensis Vozzhennikova 1967, except in lacking a sulcus.

Affinities

Definite affinities have not been demonstrated for this genus but Wall & Dale (1968a) consider it to have gonyaulacacean affinities with the apteodinioid lineage.

Genus Diconodinium Eisenack & Cookson 1960

Type Species: Diconodinium multispinum (Deflandre & Cookson) Eisenack & Cookson 1960; O.D.

Remarks

This genus has long been a puzzle with respect to its archeopyle formation. In the present study no specimen was seen which exhibited a clear archeopyle although certain broken specimens were suggestive of both precingular and intercalary archeopyles. Indeed Wall & Dale (1968a) regard the genus as having a precingular archeopyle and affinities with the Gonyaulacaceae whereas Davey (1969b) prefers to include it with the Cyst-Family Deflandreaceae (of peridiniacean affinities. Diconodinium is one of the commonest of the dinoflagellate genera encountered in the Bearpaw Formation, and it has a recorded geological range of Albian-Lower Eocene.

Diconodinium firmum sp. nov.

Plate I., Figures 4, 5, 7.

Plate X., Figure I.

Text-figure II.

Derivation of Name

Latin firmum - meaning solid, with reference to the structure of the distal extremity of the apical horn.

Diagnosis

Proximate cyst, commonly fusiform in shape, consisting of autophragm or two wall layers very closely adpressed. Test is finely granulate. Epitract extends into an apical horn having a solid distal tip which may be oblate, acuminate or bifurcate. The antapical horn is always acuminate, and is hollow throughout its entire length. The cingulum is conspicuous and takes the form of a slight laevo-rotatory helicoid. Tabulation not usually seen. Archeopyle possibly precingular of P type, and rounded polygonal in shape. (See Plate X, Figure I.).

Description

Proximate cyst, fusiform to rhomboidal. Wall of autophragm or two wall layers that are closely adpressed everywhere in the cyst. The granules of the granulation are of variable size, usually fairly fine, but are always conspicuous. The solid apical tip appears to have a definite structure (See Plate I, figure 7). It was often seen to be banded but the exact nature must await further study. The conspicuous cingulum takes the form of a laevo-rotatory helicoid and is displaced by less than one-quarter of its width. Archeopyle rounded polygonal? Very little variation was seen in this cyst species except as documented in dimensions and in the nature of the apical tip. Vozzhennikova (1967) illustrates various apical structures on Plate VII, such that it appears that this may be a useful morphological criterion in speciating this genus.

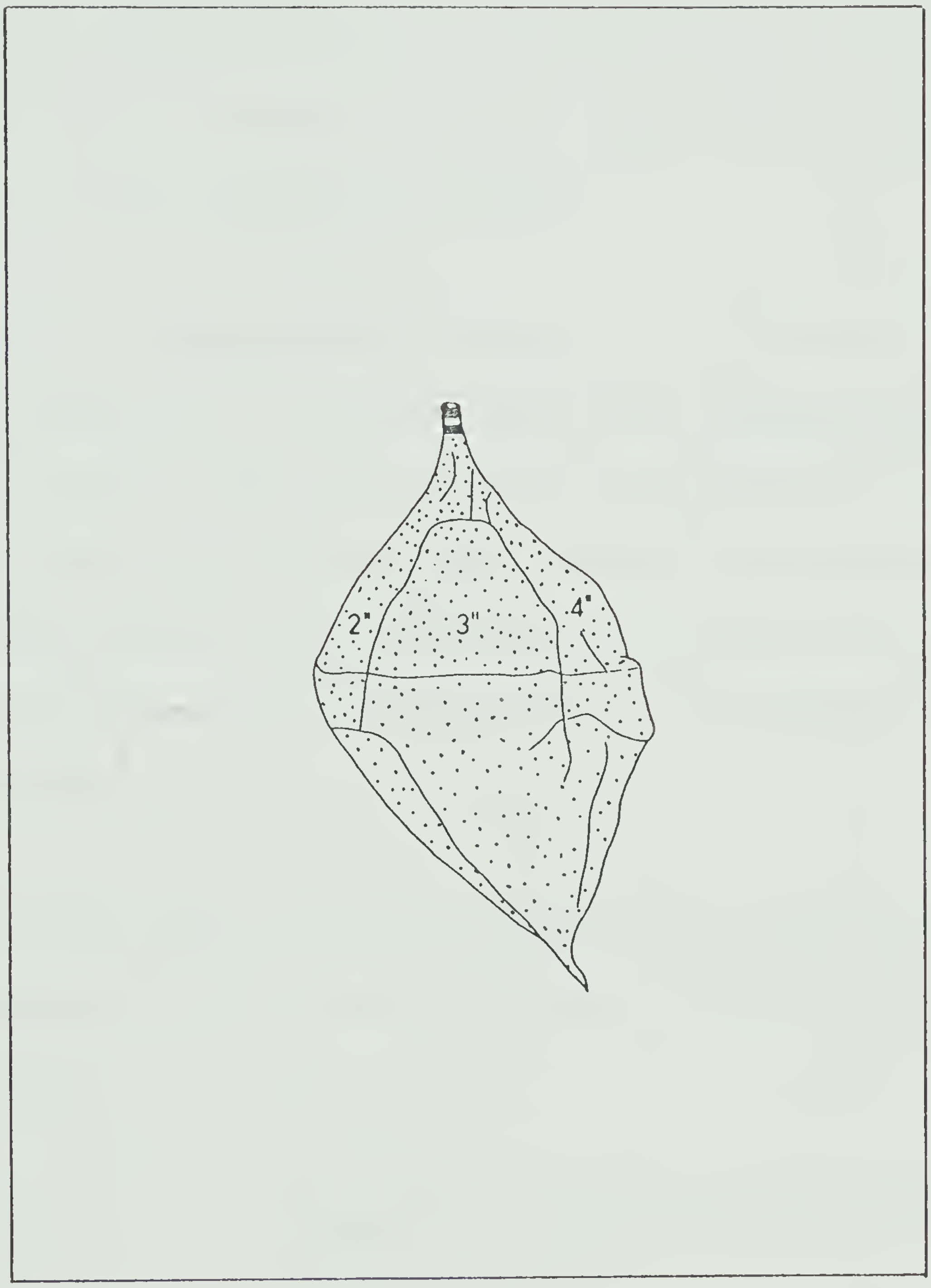

Figure 11: *Diconodinium firmum* sp. nov. Semidiagrammatic sketch of the holotype. x c. 1500

Figured Material

Holotype: JW66-13-7(2) at 98.0-32.9; Bearpaw Formation, Campanian, southern Alberta.

JW66-1-39(1) at 108.0-30.3; Bearpaw Formation, southern Alberta.

Dimensions

Holotype: Length 42.0 microns; breadth 29.0 microns. Range: length 36.0(42.7)50.0 microns; breadth 18.0(29.3)32.0 microns. Fifty specimens were measured, out of a studied population of sixty-four.

Remarks

This species is characterised by its shape and the solid structure at the distal extremity of the apical horn. This species appears close to Diconodinium rhombiformis Vozzhennikova 1967 but is different in its lack of a distinct tabulation and the lack of small gonal processes in the cingular region. Although the archeopyle was rarely observed (see Plate I, Figure 5 and Plate X, Figure 1.) the conspicuous nature of plate 3'' in many specimens of this species suggest that the archeopyle is formed by the loss of this plate.

Affinities

Wall & Dale (1968a) consider Diconodinium to have gonyaulacacean affinities and place it within the apteodinioid lineage. Definite affinities have not been demonstrated.

Diconodinium arcticum Manum & Cookson 1964

Plate I., Figure 6.

1964. Diconodinium arcticum Manum & Cookson; 18-19, pl. 6, figs. 1-4.

Description

Proximate cyst, fusiform to ovoidal, consisting of two wall layers usually closely adpressed except in some specimens where small apical and antapical pericoels are developed. The test carries a granulation which varies from a micro-

granulation to a coarse granulation. Many forms are crumpled. The epitract is elongated into a small apical horn which is oblate or bifid but never solid. The hypotract carries the usual acuminate antapical horn. The cingulum is conspicuous, three microns wide and delimited by low sutural ridges. The sulcus is also present, not conspicuous, but merely takes the expression of a break in the cingulum. The tabulation is not usually clear but in some specimens plate 3'' can be seen. The archeopyle was not observed.

Figured Material

JW66-13-1(2) at 103.6-37.1; Bearpaw Formation, southern Alberta.

Dimensions

Length 30.0(41.1)57.0 microns; breadth 20.0(26.3)37.0 microns. Fifty specimens were measured, out of a studied population of seventy-three.

Remarks

The specimens observed in the Bearpaw Formation were quite variable with regard to the granulation on the surface of the test, in some the granules were coarse in others they were fine. It was also noted that they are smaller than those described by Manum & Cookson 1964. They cannot be compared to _D. glabrum_ Eisenack & Cookson (1960) because of lacking a clearly defined sulcus and differing in the nature of the "ornamentation".

Affinities

Gonyaulacacean with the apteodinoid lineage.

Genus _Komewuia_ Cookson & Eisenack 1960

Type Species: _Komewuia glabra_ Cookson & Eisenack 1960; O.D.

Remarks

This genus was originally erected to accommodate spindle shaped _incertae sedis_ organisms. It is, however, clear that they are dinoflagellate cysts in that they

possess definite archeopyles. It is unfortunate, however, that the figures of Cookson & Eisenack (1960) are unclear as to the exact nature of the archeopyle in the original material. Wall & Dale (1968a) in their assignment of fossil cysts to probable dinoflagellate lineages, regard the archeopyle as being intercalary. The specimen described below confirms this. This genus has only previously been described from the Tithonian.

Komewuia cf. glabra Cookson & Eisenack 1960

Plate I., Figure I.

Plate X., Figure 2.

1960. ? Komewuia glabra Cookson & Eisenack; 257, pl. 39, figs. 7, 8.

Description

Proximate cyst, fusiform in shape, made up of either autophragm or closely adpressed periphragm and endophragm. Epitract somewhat bell-shaped. Test smooth to microgranulate. Apical horn is short, appears notched but may just be folded. The antapical horn is larger than the apical horn and is acuminate. A faint indication of the cingulum was the only trace of tabulation observed. Archeopyle intercalary possibly of 2I type as a small notch at the antapical border of the archeopyle might indicate the presence of two reflected intercalary plates, (See Plate X., Figure 2.), otherwise hexagonal in shape.

Figured Material

JW66-I-35(I) at 104.0-37.8; Bearpaw Formation, southern Alberta.

Dimensions

Length 148.0 microns; breadth 92.0 microns. One specimen was measured, the number of specimens studied.

Remarks

This specimen compares well with the type material which was recovered from the Tithonian of Papua and western Australia. Further study is indicated to

confirm this extended range, as it would be unwise to extend the range of this species on the evidence of one species.

Affinities

Wall & Dale (1968a) consider this genus to have peridiniacean affinities with the deflandreoid lineage. No definite affinities have been demonstrated.

Genus Lejeunia Gerlach emend.

Type Species: Lejeunia hyalina Gerlach 1961; O.D.

Emended Diagnosis

Proximate cyst, elongate, rhomboidal to pentagonal in shape, composed of autophragm. Tabulation where seen is ?4', 1a, ?7'', 4-?''', 2''''. Epitract carries a single apical horn, the hypotract carries two antapical horns, one of which may or may not be longer than the other. Cingulum is planar or takes the form of a slightly laevo-rotatory helicoid. Archeopyle unknown but possibly apical or transapical.

Remarks

This genus is emended to indicate tabulation and possible archeopyle formation as seen in the Bearpaw specimens. The possession of two antapical plates is also an important indication of a possible peridiniacean affinity. The genus is enlarged to include "Palaeoperidinium" type cysts, and it has a geological range of Santonian-Upper Oligocene.

Lejeunia parva sp. nov.

Plate I., Figures 8-10

Plate II., Figures 3, 6.

Text-figure 12.

Derivation of Name

Latin parva - meaning, small with reference to the size of the cyst.

Diagnosis

Proximate cyst, elongate to rhomboidal, made up of autophragm. Test granulate. Epitract elongated into an apical horn which is distally oblate or indented. Hypotract carries two antapical horns, one of which is larger than the other; both are distally acuminate. Cingulum, delimited by raised sutures, is planar to slightly laevo-rotatory helicoid. Tabulation ?4', la, ?7'', 4-?''', 2''''. Archeopyle not observed.

Figured Material

Holotype: RH69-13-3(2) at 99.0-31.9; Bearpaw Formation, Campanian southern Alberta.

RH69-13-3(1) at 97.0-49.2; Bearpaw Formation, southern Alberta.

JW66-13-1(1) at 103.0-36.7; Bearpaw Formation, southern Alberta.

JW66-12-64(1) at 95.0-37.0; Bearpaw Formation, southern Alberta.

Dimensions

Holotype: length 45.0 microns; breadth 30.0 microns. Range: length 34.0(44.4)57.0 microns; breadth 25.0(35.5)41.0 microns. Twenty specimens were measured, the number of specimens studied.

Description

Proximate cyst, elongate to rhomboidal, made up of autophragm i.e. one layer of the cell wall was observed. Test granulate. Apical horn has a thickened structure which may or may not be solid, but invariably shows a suture apparently bisecting the horn. The antapical horns may be well developed or one may just appear as a swelling (Plate II., figure 6.). The tabulation is variously developed and where present is delimited by raised sutures. One specimen was seen with a complete tabulation. The cingulum is usually conspicuous and is approximately

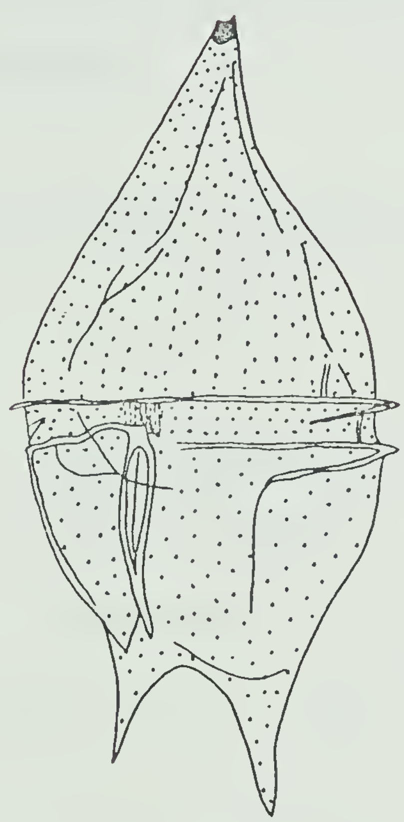

Figure 12: Lejeunia parva sp. nov. Semidiagrammatic sketch of the holotype. x c. 1875.

three microns wide and may contain granular elements that appear aligned parallel to the longitudinal axis of the cyst. Plate 3'' of the tabulation is large and conspicuous. Range of variation within this species is not great. The specimen with the tabulation is not typical for this species and so is not chosen as the holotype.

Remarks

This species is similar to that of L. tenella Morgenroth 1966. His specimens, however, lack all trace of tabulation and are much larger and more thomboidal in shape. It is also similar to Palaeoperidinium cretaceum Pocock but differs in being smaller and in not having an endoblast.

Affinities

Possible peridiniacean affinities. No definite affinities have been demonstrated.

Lejeunia tricuspis (Wetzel) comb. nov.

Plate II., Figure 4.

Frontispiece.

1933. Peridinium tricuspis Wetzel; 166, pl.2, fig. 14.

Description

Proximate cyst, elongate to rhomboidal in shape, composed of autophragm. Test smooth to microgranulate. Tabulation not visible. The epitract is conical and may be drawn out into an apical horn which is distally oblate. The hypotract, which appears divided to nearly the cingulum, carries two antapical horns, usually both are of equal length, that are distally acuminate. Many specimens have striations running sub-parallel to the longitudinal axis of the cyst. The cingulum is always conspicuous, defined by raised sutures, approximately four microns in width, shallow and planar. The archeopyle not observed.

Figured Material

JW66-10-13(I) at 99.0-29.9; Bearpaw Formation, southern Alberta.

Dimensions

Length 80.0(104.3)135.0 microns; breadth 52.0(73.8)95.0 microns. Sixteen specimens were measured, the number of specimens studied.

Remarks

The Bearpaw specimens of this species compare well with those of Wetzel (1933). The author considers that *Lejeunia kozlowskii* Gorka 1963 is a junior synonym of this species. Gorka (1963) figures both *L. kozlowskii* and *L.* cf. *tricuspis*. It appears that any difference between the two can be accommodated by specific variation. *Lejeunia tricuspis* has a geological range of Santonian – Maestrichtian.

Affinities

?Peridiniacean. No definite affinities have been demonstrated.

?*Lejeunia ampla* sp. nov.

Plate II., Figures 1, 2, 5.

Text-figure 13.

Derivation of Name

Latin *ampla* – meaning large, with reference to the overall size of this species.

Diagnosis

Proximate cyst, rhomboidal in shape, probably made up of autophragm only. Test granulate, scabrate and/or reticulate. No tabulation visible. Cingulum usually conspicuous, planar, approximately five microns wide, delimited by raised sutures. Single apical horn, distally oblate; two antapical horns one of which is generally larger than the other. Archeopyle apical.

Figured Material

Holotype: JW66-13-13(1) at 95.8-37.0; Bearpaw Formation, Campanian southern Alberta.

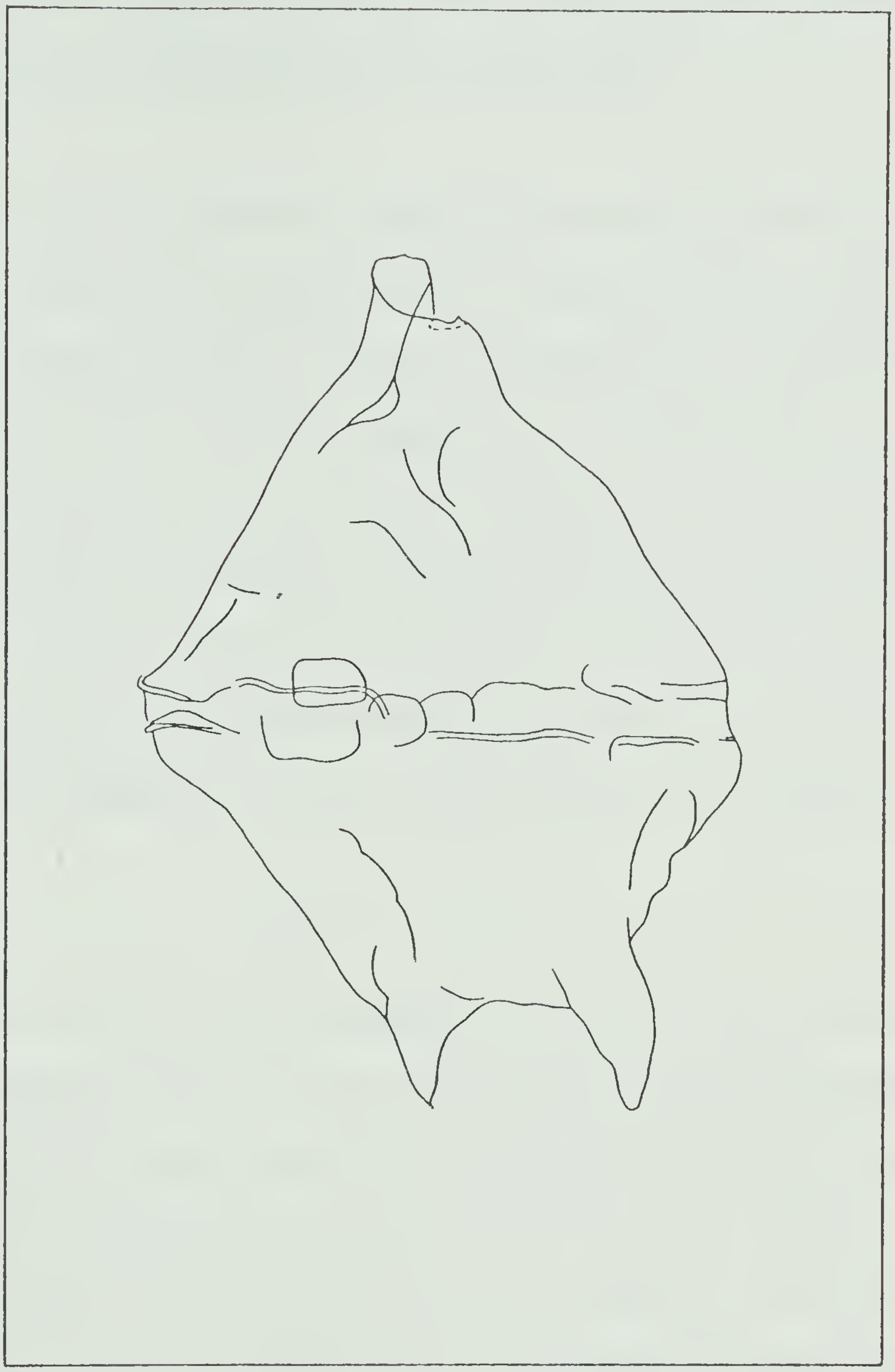

Figure 13: ?*Lejeunia ampla* sp. nov. Semidiagrammatic sketch of the holotype. x c. 725.

JW66-12-28(I) at 108.1-39.5; Bearpaw Formation, southern Alberta.

Dimensions

Holotype: length 149.0 microns; breadth 108.0 microns. Range: length 70.0(116.3)154.0 microns; breadth 68.0(97.0)108.0 microns. Fifty specimens were measured out of a studied population of eighty-nine.

Description

Proximate cyst, rhomboidal in shape although some are slightly elongate; the cyst appears made up of an autophragm but it is possible that a second wall layer, closely adpressed is present. The test "ornamentation" is variable from granulate, scabrate and/or reticulate. Apical horn is distally oblate where complate. One or two specimens have an apical archeopyle. Norris (pers. comm.) has observed transapical archeopyles in specimens with the same gross morphology. The Bearpaw specimens appear to have had one or two antapical plates making up the operculum. The antapical horns are distally evexate and one was seen to carry small spinules. The cingulum is variable, usually conspicuous, delimited by raised sutures.

Remarks

This species differs from _L. tricuspis_ in lacking the vertical striations, lacking the acuminate antapical horns and lacking the coarse "ornamentation". Doubt is expressed in the generic assignment of this species because of uncertaintities in the nature of the archeopyle in this species and in the genus. The archeopyle as seen in the holotype is perfectly clear and does not appear to be of accidental origin. Evitt (pers. comm.) has commented on the resemblance of the small folds, often observed on the test of these cysts and as seen in Plate II., figure 2, to growth lines such as those exhibited by _Palaeoperidinium pyrophorum_ (Ehrenberg). In no specimen were growth lines seen nor was an epitractal archeopyle ever observed.

Affinities

Unknown.

Genus Spinidinium Cookson & Eisenack 1962

Type Species: Spinidinium styloniferum Cookson & Eisenack 1962; O.D.

Remarks

Spinidinium is characterised by the possession of "spines". It is, however, morphologically similar to Deflandrea in that it is cavate and possesses an intercalary archeopyle. Wilson (1967) has placed certain spiny specimens in the genus Deflandrea and certainly a review of the situation is indicated as Deflandrea is presently defined to include only forms with smooth or granulate tests. The form described below appears close to the genera Diconodinium and Spinidinium but because of the possession of two antapical horns and a clearly cavate morphology it is placed in Spinidinium. The genus has a geological range Aptian-Palaeocene.

Spinidinium clavus sp. nov.

Plate III., Figures 6, 7, 8, 11.

Text-figure 14.

Derivation of Name

Latin clavus - meaning spike, with reference to the development of short, acuminate processes along the sutural crests.

Diagnosis

Cavate cyst, fusiform in shape, made up of two wall layers closely adpressed except at the apex and antapex where pericoels may be evident. Test usually smooth with the presence of occasional discrete granules. Epitract slightly more conical than the hypotract. Prominent apical horn, tapering with a bifid tip; antapical horns acuminate. Sutural ridges, up to five microns tall, carry short oblate and

acuminate processes. Certain plate areas of the tabulation may be delimited due to sutural development. A tabulation ?4', la, ?7'', ?4c, 5-6''', ?2'''' is indicated. Cingulum planar, sulcus conspicuous extending onto both the epitract and hypotract. Archeopyle indeterminate, but it is almost certain that loss of the conspicuous intercalary plate forms the archeopyle.

Description

Cavate cyst, often appears proximate because of poor pericoel development. Cyst fusiform, made up of two wall layers closely adpressed with an apical and antapical pericoel usually developed. The holotype shows this feature well but in other specimens of the same species small pericoels were developed. The apex appears to be made up of four apical plates which are separated by large sutural ridges, characteristic of this species. These ridges add to the prominence of the apex. The crests of the ridges carry small oblate and acuminate processes. The precingular plate series appears to consist of five to seven plates, of which plate 4'' is conspicuous and polygonal in shape, directly above this plate there is a single rectangular anterior intercalary plate. The cingulum is conspicuous, appears nearly planar and is often the focus for folding and crumpling of the cyst. The sulcus is also usually present and appears as a broad area extending onto both the epitract and hypotract. The post-cingular plate series appears to comprise five or six plates but only certain indeterminate plate boundaries were seen. The hypotract is more rounded than the epitract but it is of interest that the sutural crests are better developed on the epitract that on the hypotract. The range of variation of this species is well seen in the plates. The most variable feature is the size of the endoblast in relation to periblast.

Figured Material

Holotype: JW66-5-l(l) at 95.0-40.l; Bearpaw Formation, Campanian, southern Alberta.

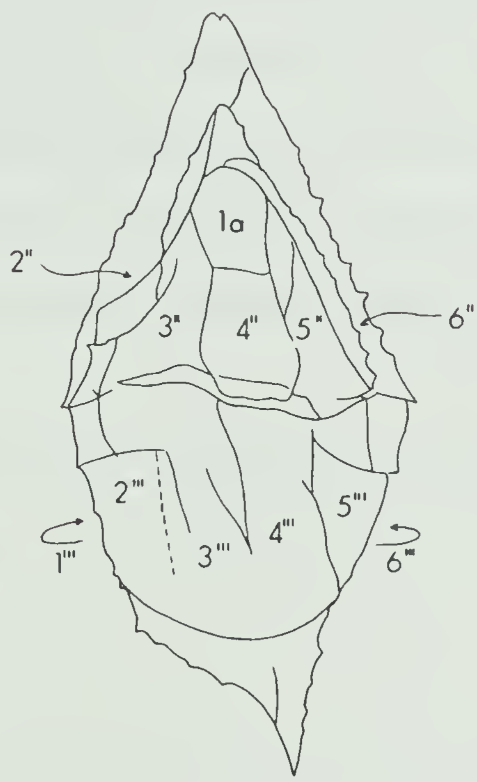

Figure 14: Spinidinium clavus sp. nov. Semidiagrammatic sketch of the holotype. x c. 1425.

JW66-5-1(1) at 94.0-28.0; Bearpaw Formation, southern Alberta.

JW68-2-1(2) at 94.7-38.0; Bearpaw Formation, southern Alberta.

JW68-2-1(1) at 104.0-32.1; Bearpaw Formation, southern Alberta.

Dimensions

Holotype: Length 51.0 microns; breadth 29.0 microns. Range: length 40.0(45.3)60.0 microns; breadth 20.0(26.0)35.0 microns. Seventeen specimens were measured, the number of specimens studied.

Remarks

This species is characterised by the nature of the large sutural ridges. It is similar to Palaeoperidinium caulleryi Deflandre 1934 which Deflandre (1966) considers to be a member of the genus Diconodinium. It was not, however, formally recombined (re. Article 33 of I.C.B.N.). Singh (pers. comm.) is of the opinion that all spiny cavate cysts should be included in the genus Deflandrea.

Affinities

Wall & Dale (1968a) consider Spinidinium to have peridiniacean affinities with the deflandreoid lineage. Definite affinities have not been demonstrated.

Cyst-Family Microdiniaceae Eisenack emend. Sarjeant & Downie 1966

Genus Microdinium Cookson & Eisenack emend.
Sarjeant 1966.

Type Species: Microdinium ornatum Cookson & Eisenack 1960; O.D.

Remarks

This genus was emended by Sarjeant (1966) to clarify the nature of the tabulation and archeopyle formation. The genus has a geological range Albian-Maestrichtian.

Microdinium cf. irregulare Clarke & Verdier 1967

Plate III., Figures 13, 14.

1967. ?Microdinium irregulare Clarke & Verdier; 65-66, pl. 7, figs. 5-8, text-fig. 27.

Description

Proximate cyst, spheroidal to ovoidal in shape, composed of periphragm and endophragm closely adpressed. The periphragm makes up the sutural crests that are large and conspicuous. Cyst is microgranulate to granulate except for the crests which are smooth. The tabulation is clear. The cingulum is three to four microns wide, planar or weakly helicoidal in nature. Epitract is small in comparison to the hypotract, the tabulation is difficult to decipher because of the granules and crests but 6''', lp, 1'''', were observed. Epitractal details are especially difficult to see. The archeopyle is apical of $\overline{A}$ type, and is probably formed by the loss of three or four apical plates (Evitt pers. comm.). No opercula were discovered in the Bearpaw assemblages that could be attributable to this species.

Figured Material

JW66-5-1(2) at 100.0-43.3; Bearpaw Formation, southern Alberta.

JW66-9-4(2) at 94.0-32.6; Bearpaw Formation, southern Alberta

Dimensions

Length 24.0(34.5)39.0 microns; breadth 26.0(32.6)38.0 microns.

Thirty-six specimens were measured, the number of studied specimens.

Remarks

These specimens compare well with those described by Clarke & Verdier (1967) but a full comparison is not possible because of the poor quality of their microphotographs. This species had a geological range Cenomanian-Santonian (Clarke & Verdier op. cit.).

Affinities

Wall & Dale (1968a) consider this genus to have gonyaulacacean affinities

and they place it with the lithodinioid lineage. No definite affinities have been demonstrated.

Cyst-Family Uncertain

Genus Dinogymnium Evitt et al. 1967

Type Species: Dinogymnium acuminatum Evitt et al. 1967; O.D.

Remarks

This genus was erected by Evitt et al. (1967) to accommodate Gymnodinium-like dinoflagellate cysts possessing a very distinct apical archeopyle and wall canals. Many cysts previously assigned to Gymnodinium Stein were reattributed to this genus. Species included in Dinogymnium have a large specific variability. Evitt et al. (op.cit), however, found that a statistical parameter called the cingulum index (CI), i.e. length from apex to middle of the cingulum, divided by the total cyst length multiplied by 100, to be of taxonomic value. The recorded geological range of this genus is Upper Cretaceous - ?Paleocene (Evitt et al., op. cit.).

Dinogymnium cf. albertii Clarke & Verdier 1967

Plate III., Figure 4.

1967. ?Dinogymnium albertii Clarke & Verdier; 33, pl. 17, figs. 3-4, text-fig. 13.

Description

Proximate cyst, subspheroidal to ovoidal in shape, the epitract more conical than the hypotract, made up of two wall layers closely adpressed. Test carries a number of longitudinal grooves, that are commoner on the epitract that on the hypotract. In addition, the test is perforated by many micropunctae (wall canals). Tabulation not present except for a very conspicuous deep cingulum which is four

microns wide, and takes the form of a laevo-rotatory helicoid. The test is often crumpled along this feature. Displacement is approximately equal to half the width of the cingulum. Sulcus also present but only on the hypotract. Archeopyle apical, regarded as miscellaneous by Evitt (1967), formed by loss of a ? single plate at the very tip of the epitract.

Figured Specimen

JW66-1-37(I) at 105.7-42.0; Bearpaw Formation, southern Alberta.

Dimensions

Length 40.0(41.3)42.0 microns; breadth 20.0(22.0)25.0 microns, cingulum index 50.0(52.3)55.0. Three specimens were measured, the number of specimens studied.

Remarks

This species is compared to D. albertii Clarke & Verdier 1967 by virtue of the presence of punctae and in its general form. It differs, however, in size, being smaller, and in this appears fairly close to Gymnodinium albertii Vozzhennikova 1967. It was previously recorded from the Santonian by Clarke & Verdier (op.cit.).

Affinities

In general morphology the genus closely resembles the modern genus Gymnodinium, with which it has often been confused. The affinities of this dinoflagellate cyst are as yet unknown.

Dinogymnium longicornis (Vozzhennikova) nov. comb.

Plate III., Figures 1, 2, 3.

1967. Gymnodinium longicornis Vozzhennikova; 46. pl. 1, fig. 8, pl.3, fig. 6, pl. 4, figs. 6a, 6b, 7.

Description

Proximate cyst, ovoidal to markedly elongate, made up of two closely adpressed wall layers. Test carries some longitudinal grooves and a fine micropunctation

which is better developed in some specimens than others. The epitract is conical to very elongate, drawn out into a long apical horn. The hypotract is always hemispheroidal. A conspicuous cingulum is always present, approximately two microns wide, in the form of a laevo-rotatory helicoid which is displaced by up to twice its width. A sulcus is present on the hypotract only. Faint sutural ridges are sometimes present delimiting a possible tabulation; a possible reflected plate Ip was observed in one specimen. Archeopyle apical, typical for the genus.

Figured Material

JW66-I-20(3) at 102.0-29.3; Bearpaw Formation, southern Alberta.

JW66-I-24(3) at 107.9-36.3; Bearpaw Formation, southern Alberta.

Dimensions

Length 39.0(49.4)59.0 microns; breadth 19.0(27.3)33.0 microns, cingulum index 58.0(65.75)75.0. Eleven specimens were measured, the number of specimens studied.

Remarks

This species is very similar to that figured by Vozzhennikova (1967); there can be no doubt that the species belongs to the genus *Dinogymnium* as in Vozzhennikova's figures the archeopyle is perfectly evident. The specimens from the Bearpaw Formation seem more variable than those of Vozzhennikova (op.cit.) and are generally smaller. The Russian specimens are Senonian in age and were recovered from western Sibera.

Affinities

Unknown.

Cyst-Family Fromeaceae Sarjeant & Downie 1966

Genus Membranosphaera Samoylovich ex. Norris & Sarjeant emend. Drugg 1967.

Type Species: Membranosphaera maastrichtica Samoylovich ex. Norris & Sarjeant, 1965; S.D.

Remarks

This genus was originally described as a "gruppa" by Samoylovich (1961) and as such was not validated until 1965 when Norris & Sarjeant assigned a description to the genus and gave reference to previous descriptions and figures. Drugg (1967) emended the generic diagnosis to note the apical archeopyle. The genus had a previously defined geological range of Maestrichtian-Danian.

?Membranosphaera cf. maastrichtica
Samoylovich ex. Norris & Sarjeant emend.
Drugg 1967.
Plate III., Figure 15.

1961. ?Membranosphaera maastrichtica Samoylovich, (in Samoylovich et al. 252, pl. 83, figs. 1, 2.

1965. ?Membranosphaera maastrichtica Samoylovich ex. Norris & Sarjeant; 40

1967. ?Membranosphaera maastrichtica Samoylovich ex. Norris & Sarjeant emend. Drugg; 29-30, pl. 5, figs. 12-13.

Description

Proximate cyst, spheroidal to ovoidal in shape, composed of endophragm and periphragm. The endophragm makes up small cylindrical capitate processes

that appear to support an outer membraneous periphragm. A faint trace of the cingulum may be observed, it appears planar, is approximately three microns in width and is delimited by areas devoid of endophragmal processes. No other tabulation is discernable. The archeopyle is apical, possibly of a type formed by the loss of a single apical plate; the sulcal notch was observed.

Figured Material

JW66-9-5(3) at 103.0-34.3; Bearpaw Formation, southern Alberta.

Dimensions

Length 28.0(30.0)32.0 microns; breadth 27.0(27.5)28.0 microns. Two specimens were measured, the number of specimens studied.

Remarks

The Bearpaw specimens differ from those of Drugg (1967) in possessing a faint cingulum and a smaller apical archeopyle. There is also no rupture between plates of the precingular series as figured by Drugg (op. cit.). This species had a previous geological range of Maestrichtian-Danian (Drugg, op. cit.). Singh (pers. comm.) points out that these specimens are close to specimens of Gardodinium eisenacki Alberti 1961 that have lost their apex. It is unfortunate that the lack of further specimens precludes a more precise identification.

Affinities

Unknown

Cyst-Family Canningiaceae Sarjeant & Downie 1966

Genus *Canningia* Cookson & Eisenack 1960

Type Species; *Canningia reticulata* Cookson & Eisenack 1960; O.D.

Remarks

This genus has a recorded geological range Tithonian-Campanian, and is characterised by its simple morphology and apical archeopyle.

Canningia senonica Clarke & Verdier 1967

Plate III., Figures 9, 10.

1967. *Canningia senonica* Clarke & Verdier; 20-21, pl. I., figs. 12-14, text-fig.7.

Description

Proximo-chorate cyst, ovoidal to triangular in shape and composed of two wall layers. These are closely adpressed except at the bases of the processes where the periphragm separates to make up the processes. The test is microgranulate. No tabulation was seen, the processes appear randomly distributed. Processes are short, slender to latispinous, erect, cylindrical to tapering and distally branched and bifurcate. In plan the processes give the appearance of a reticulation. The archeopyle is apical, of the $\bar{A}$ type with a sulcal notch being present in some specimens.

Figured Material

JW66-5-7(3) at 103.0-30.0; Bearpaw Formation, southern Alberta.

JW66-1-39(1) at 109.0-28.2; Bearpaw Formation, southern Alberta.

Dimensions

Length 36.0(48.0)67.0 microns; breadth 40.0(51.5)63.0 microns, the processes range in length from 2-8 microns. Four specimens were measured, the number of specimens studied.

Remarks

It was noticed in the specimens attributed to this species that there was considerable variation with regard to process development and the apparent reticulation.

This species was previously only reported from the Senonian of the Isle of Wight, England, by Clarke & Verdier (1967).

Affinities

Definite affinities have not been demonstrated, but Wall & Dale (1968a) postulate that it has gonyaulacacean affinities with the lithodinioid lineage.

Canningia cf. rotundata Cookson & Eisenack 1961

Plate III., Figure 12.

1961. ?Canningia rotundata Cookson & Eisenack; 72, pl. 12., figs. 1-5.

Description

Proximate cyst, ovoidal to spheroidal in shape, being composed of only one observable wall layer that is smooth to microgranulate. Ridges are also present but these do not appear to outline a tabulation except in one limited area where they appear to delimit a cingulum. The archeopyle is apical of the $\bar{A}$ type. The appearance of ruptures around the archeopyle suggest the presence of six reflected precingular plates.

Figured Material

JW66-1-33(2) at 104.0-36.4; Bearpaw Formation, southern Alberta.

Dimensions

Length 41.0 microns; breadth 47.0 microns. One specimen was measured, the number of specimens studied.

Remarks

This species, like C. senonica has previously only been recorded from the Senonian. The observed specimen is morphologically similar to the figured holotype but differs primarily in the nature of the "ornamentation". The holotype has a vermiculate "ornamentation". It is not unconceivable that this specimen is part of the specific variation of C. senonica but in the assemblage under study no transitional specimens between C. senonica and C. cf. rotundata were observed.

Affinities

Probably gonyaulacacean with the lithodinioid lineage. No definite affinities have been demonstrated.

Cyst-Family Pyxidiellaceae Sarjeant & Downie 1966

Genus Uvatodinium Vozzhennikova 1963

Type Species: Uvatodinium nasutum Vozzhennikova 1963; O.D.

Remarks

This genus is characterised by the possession of a single apical horn and a coarse reticulation. Vozzhennikova (1967) illustrates a specimen with a clear intercalary archeopyle. The genus was previously restricted to the Paleocene, although the range should not be dogmatically extended on the evidence below.

?Uvatodinium cf. nasutum Vozzhennikova 1963

Plate III., Figure 5.

1963 ?Uvatodinium nasutum Vozzhennikova; 182, fig. 13a, 13b.

Description

Proximate cyst, subspheroidal in shape, composed of periphragm and endophragm closely adpressed; the former makes up the "ornamentation". Test granulate. Epitract bears an apical horn which is distally evexate. In addition the epitract bears a distinct "shoulder". The hypotract carries a slight antapical boss. The cingulum is conspicuous, delimited by raised sutures, and takes the form of a laevo-rotatory helicoid and is displaced by half the width of the cingulum which is four to five microns wide. A sulcus is present, delimited by raised sutures, and is confined to the hypotract. No other tabulation is present. Archeopyle is intercalary

of the I type.

Figures Material

JW66-5-7(I) at 99.0-29.6; Bearpaw Formation, southern Alberta.

Dimensions

Length 61.0(68.0)75.0 microns, breadth 54.0(57.6)60.0 microns.

Three specimens were measured, the number of specimens studied.

Remarks

These specimens compare quite well with those illustrated by Vozzhennikova (1967) except in lacking the coarse reticulation; although in pl. 8., fig. 4. the reticulation is not at all obvious. If "ornamentation" is regarded as being taxonomically unstable at generic level as Well & Dale (1968a) would suggest then these specimens do in fact belong to this genus. Further studies should clear up these uncertainties. This species has only been recorded from the Paleocene (Vozzhennikova 1967).

Affinities

Unknown

Cyst-Family Hystrichosphaeridiaceae Evitt emend. Sarjeant & Downie 1966.

Genus Hystrichosphaeridium Deflandre emend. Davey & Williams 1966b.

Type Species: Hystrichosphaeridium tubiferum (Ehrenberg) Deflandre 1937; O.D.

Remarks

The emendation of Davey & Williams (1966b) restricts the genus to those forms possessing a tabulation of 4'(-5'), 6'', 6c, 5-6''', Ip, I'''', and open processes.

Many of the species are consequently erected on process morphology such that species limits are difficult to recognise. It is, therefore, best to regard this genus as encompassing a complex of morphological types. The genus has a geological range of Barremanian-Middle Miocene.

<u>Hystrichosphaeridium</u> cf. <u>arborispinum</u>
Davey & Williams 1966b.
Plate IV., Figures 2, 4.

1966b ?<u>Hystrichosphaeridium</u> <u>arborispinum</u> Davey & Williams; 61, pl. 9, figs. 5, 10.

Description

Chorate cyst, subspheroidal to ovoidal in shape, made up of both periphragm and endophragm, the former making up the processes. Cyst is smooth to microgranulate. The processes are intratabular and reflect the tabulation 6'', 6c, 5''', 1''''; they are hollow, slender to latispinous, erect, cylindrical and distally flared. The distal extremities are recurved, digitate to serrate. In many specimens the processes appear fibrous. Additional cylindrical recurved and digitate sutural processes are present in many specimens. The archeopyle is apical of the $\bar{A}$ type.

Figured Material

JW66-5-1(3) at 93.0-30.5; Bearpaw Formation, southern Alberta.

JW66-1-39(2) at 107.0-33.8; Bearpaw Formation, southern Alberta.

Dimensions

Long axis of cyst 29.0(40.0-52.0 microns; short axis of cyst 30.0(38.35) 55.0 microns, processes range in length from 11-25 microns. Twenty specimens were measured, the number of specimens studied.

Remarks

This species is generally fairly common in the Bearpaw assemblages and may be recognised by the character of its processes. It has a geological range Lower

Barremian-Middle Barremian.

Affinities

The tabulation indicates a gonyaulacacean affinity. Wall & Dale (1968a) place members of the genus Hystrichosphaeridium in the hystrichosphaeridioid lineage. No definite affinities have been demonstrated.

Hystrichosphaeridium dowlingii sp. nov.

Plate IV., Figure 3.

Text-figure 15.

Derivation of Name

Named in honour of D. B. Dowling, one of the first geologists to work in southern Alberta.

Diagnosis

Chorate cyst, spheroidal in shape, made up of periphragm and endophragm. Test microgranulate. Tabulation 6'', 6c, 6''', 1-2p, 1''''. Processes are hollow, slender to latispinous, erect to curved, cylindrical, distally flared and fenestrate. Archeopyle of the $\bar{A}$ type.

Figured Material

Holotype: JW66-1-39(2) at 106.0-33.9; Bearpaw Formation, Campanian, southern Alberta.

Dimensions

Holotype: Long axis of cyst 44.0 microns; short axis of cyst 38.0 microns, processes range in length from 15-24 microns.

Range: Long axis of cyst 25.0(34.4)46.0 microns; short axis of cyst 29.0 (34.0)54.0 microns, processes range in length from 10-28 microns. Twelve specimens were measured, the number of specimens studied.

Description

Chorate cyst, spheroidal to ovoidal in shape, made up of periphragm and

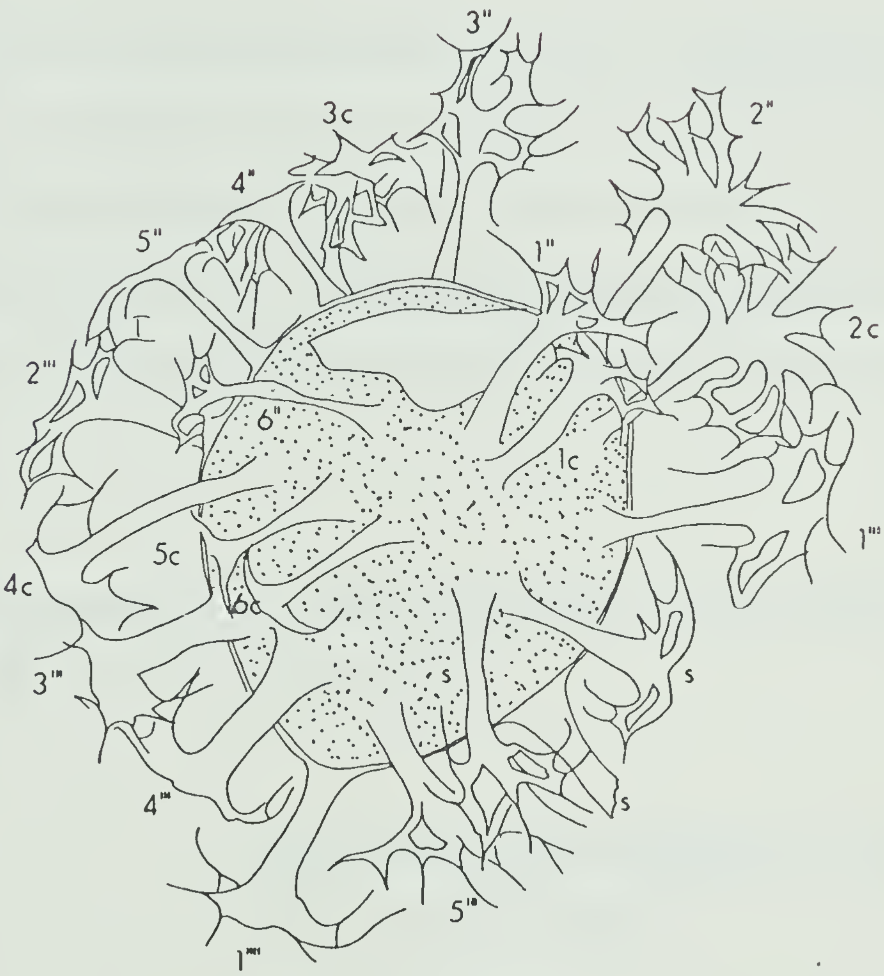

Figure 15: Hystrichosphaeridium dowlingii sp. nov. Semidiagrammatic sketch of the holotype. x c. 1135.

endophragm closely adpressed. The former makes up the processes which do not appear to connect to the interior of the cyst. Test is microgranulate but this "ornament" does not extend onto the process shafts. The processes are characterised by their fenestrate nature. The sulcal area is devoid of all processes except for a group of three sulcal processes. The archeopyle has a zig-zag margin and is of the $\bar{A}$ type. A sulcal notch may also be seen in some specimens.

Remarks

This species is easily distinguishable from H. cf. arborispinum by the nature of the processes i.e. fenestrate nature and lack of "ornamentation" of the processes shafts. The test "ornamentation" is also much coarses than that of H. cf. arborispinum. This species is superficially similar to Oligosphaeridium pulcherrimum (Deflandre & Cookson) Davey & Williams 1966b especially with regard to the nature of the processes.

Affinities

Gonyaulacacean with the hystrichosphaeridioid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Hystrichosphaeridium tubiferum var. brevispinum
Davey & Williams 1966b.
Plate IV., Figure 9.

1966b. Hystrichosphaeridium tubiferum var. brevispinum. Davey & Williams, 58, pl. 10, fig. 10.

Description

Chorate cyst, subspheroidal to ovoidal in shape. Test composed of periphragm and endophragm closely adpressed, the former making up the processes. Test smooth to microgranulate. Processes intratabular and reflect a tabulation of 6'', 6c, 5''', 1-2p, 1''''. Four sulcal processes are also present. Processes are hollow, the intra-tabular ones are latispinous, the sutural ones slender; all are erect to curved, smooth,

cylindrical, distally flared, recurved with a denticulate extremity. The sulcal processes are recurved, digitate to entire. The archeopyle is apical of the $\bar{A}$ type and has a zig-zag margin and a distinct sulcal notch.

Figured Material

JW66-1-39(1) at 101.0-31.3; Bearpaw Formation, southern Alberta.

Dimensions

Long axis of cyst 25.0(31.2)38.0 microns; short axis of cyst 25.0(30.6)38.0 microns, processes range in length 6-15 microns. Twenty specimens were measured, the number of specimens studied.

Remarks

This variety compares well with those specimens described by Davey & Williams (1966b). The Bearpaw specimens were, however, smaller in size with a slightly more variable process habit. The variety is characterised by process length.

Affinities

Gonyaulacacean with the hystrichosphaeridioid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Hystrichosphaeridium salpingophorum (Deflandre) emend.

Davey & Williams 1966b.

Plate IV., Figures 5, 6.

1935. Hystrichosphaera salpingophora Deflandre; 232, pl. 9, fig. 1.

1966b. Hystrichosphaeridium salpingophorum (Deflandre) emend. Davey & Williams; 61-62, pl. 10, fig. 6.

Description

Chorate cyst, spheroidal to subspheroidal in shape, cell wall composed of periphragm and endophragm closely adpressed; the former making up the processes.

Cyst smooth to microgranulate. Tabulation as deciphered from the intratabular processes appears to be 6'', 6c, 5''', lp, l-5s, l''''. Processes are hollow, latispinous, erect, cylindrical becoming flared distally. Extremities are entire or with patulate or digitate appearance. Some process shafts appear fibrous. Archeopyle of $\bar{A}$ type with a zig-zag margin and a prominent sulcal notch.

Figured Material

JW66-1-39(2) at 99.0-36.0; Bearpaw Formation, southern Alberta.

JW66-10-5(3) at 92.0-40.6; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 31.0(38.8)44.0 microns; length of short axis 29.0 (35.75)48.0 microns, processes range in length from 10-18 microns. Nine specimens were measured, the number of specimens studied.

Remarks

This species compares well with those specimens figured by Davey & Williams (1966b). There is an obvious morphological overlap with H. tubiferum var. brevispinum but usually the two species can be recognised. The species has a geological range of Upper Jurassic-Lower Eocene. Evitt (pers.comm.) feels that this species is the same as H. tubiferum (Ehrenberg). In the present study specimens described above are felt to be closer to H. salpingophorum in morphology and are so designated.

Affinities

Gonyaulacacean with the hystrichosphaeridioid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Genus Cleistosphaeridium Davey et al. 1966

Type Species: Cleistosphaeridium diversispinosum Davey et al. 1966; O.D.

Remarks

This genus was erected to accommodate Mezozoic and Tertiary palynomorphs, formerly attributed to the genus Baltisphaeridium, that possess an apical archeopyle but cannot be attributed to the genera Surculosphaeridium Davey et al. (op. cit.) or Prolixosphaeridium Davey et al. (op.cit.). The recorded geological range for the genus is Bathonian-Holocene.

Cleistosphaeridium diversispinosum Davey et al.
1966.
Plate IV., Figure I.

1966. Cleistosphaeridium diversispinosum Davey et al. 167, pl. 10, fig. 7.

Description

Chorate cyst, spheroidal to ovoidal in shape. Test composed of two wall layers, the periphragm constructing the process. The test is microgranulate, granulate or smooth. No trace of tabulation was observed, the processes appear distributed at random over the surface of the cyst. The processes are long, slender, erect to sinuous, cylindrical to tapering, distally they are usually bifurcate with one of the portions longer than the other. The bifurcation is often accompanied by some expansion of the process. Archeopyle is apical, probably of the $\bar{A}$ type and in some specimens the sulcal notch was observed.

Figured Material

JW66-9-5(I) at 95.0-43.4; Bearpaw Formation, southern Alberta.

Dimensions

Length 35.0(48.75)57.0 microns; breadth 43.0(52.25)67.0 microns, processes range in length from 5-19 microns. Nine specimens were measured, the number of specimens studied.

Remarks

It is obvious from the above description, in comparison to that of Davey

et al. (1966), that the writer considers there is a wider specific variation than that observed by Davey *et al.* (1966). The processes are variable in thickness, sinuousity, length and in the structural diversity of their extremities. This species was previously only recorded from the Eocene.

Affinities

Until the nature of the ornamentation is better understood no affinities are suggested.

Cleistosphaeridium sp. A

Plate IV., Figure 7.

Description

Chorate cyst, subspheroidal in shape, made up of two wall layers; the periphragm makes up the processes. The test carries granules but no trace of tabulation could be discerned, as the processes appear randomly dispersed. The processes are slender to latispinous, curved to sinuous, cylindrical to tapering. Most processes end in an equal distal bifurcation but others are acuminate and oblate. Archeopyle is apical, of the $\bar{A}$ type.

Figured Material

RH69-13-3(1) at 98.0-46.5; Bearpaw Formation, southern Alberta.

Dimensions

Length 35.0(39.0)43.0 microns; breadth 39.0(40.5)42.0 microns, processes range in length from 8-11 microns. Two specimens were measured, the number of specimens studied.

Remarks

This species is similar to ? *Cleistosphaeridium flexuosum* Davey *et al.* 1966 but differs in process length and in the nature of the processes extremities.

Affinities

Unknown.

Genus Coronifera Cookson & Eisenack emend. Davey 1969a

Type Species: Coronifera oceanica Cookson & Eisenack 1958; O.D.

Remarks

The generic diagnosis was emended by Davey (1969a) to recognise the presence of an apical archeopyle and low crests joining the processes. The genus has a geological range of Albian-Cenomanian.

? Coronifera oceanica Cookson & Eisenack 1958

Plate IV., Figure 8.

1958. ?Coronifera oceanica Cookson & Eisenack; 45, pl. 12, figs. 5-6.

Description

Proximate cyst, spheroidal in shape. Test is composed of two wall layers closely adpressed of which the periphragm alone makes up the processes. Cyst wall is microgranulate and is covered by numerous processes, seemingly at random. The processes do not connect to the interior of the cyst and are slender, curved, cylindrical to tapering and distally acuminate. No tabulation could be discerned. The cyst carries a single large antapical process which is latispinous, erect, distally open with an entire or denticulate margin, this process is very characteristic of the species and genus. No archeopyle was observed.

Figured Material

JW66-12-28(l) at 106.7-46.0; Bearpaw Formation, southern Alberta.

Dimensions

Length 33.0(37.5)42.0 microns; breadth 31.0(40.5)50.0 microns, the processes range in length from 4-10 microns. Two specimens were measured, the number of specimens studied.

Remarks

The specimens under consideration differ from those of Davey (1969a) in lacking any kind of sutural ridges or clear apical processes. This is probably a

consequence of specific variation. Lack of the presence of an archeopyle casts some doubt on the identification of this species. The presence of an $\bar{A}$ archeopyle would suggest that these specimens be placed in the genus Diphyes Cookson 1965.

Affinities

Probably gonyaulacacean by virtue of the single antapical process, suggesting the possession of a single antapical plate. Millioud (1969) reported the presence of a precingular archeopyle in a new species of Coronifera from the Upper Hauterivian of Angles, S.E. France. This suggests that Coronifera should be attributed to the hystrichodinioid lineage.

Forma a

Plate V., Figures 1,2,3,4, & 6.

Text-figure 16.

Description

Chorate cyst, ovoidal to elongate in shape. Test consists of a thick (1.0-1.5 microns) endophragm and a thin periphragm. Test is smooth to microgranulate. Endoblast appears made up of discrete chambers giving the cyst a globular or globate appearance. Two whorls of lobes are present separated by a cingular groove which is in the form of a laevo-rotatory helicoid. Processes intratabular, reflecting a possible tabulation of ?7'' and 5 or 6'''. They do not connect to the interior of the cyst and are constructed of periphragm. No antapical processes are present. Archeopyle is apical with an attached operculum, possibly of the $\bar{A}$a type.

Figured Material

JW66-12-36(3) at 107.2-35.9; Bearpaw Formation, southern Alberta.

Dimensions

Range: Length 32.0(37.5)43.0 microns; breadth 25.0(29.5)34.0 microns, processes range in length from 20-25 microns. Two specimens were measured, the number of specimens studied.

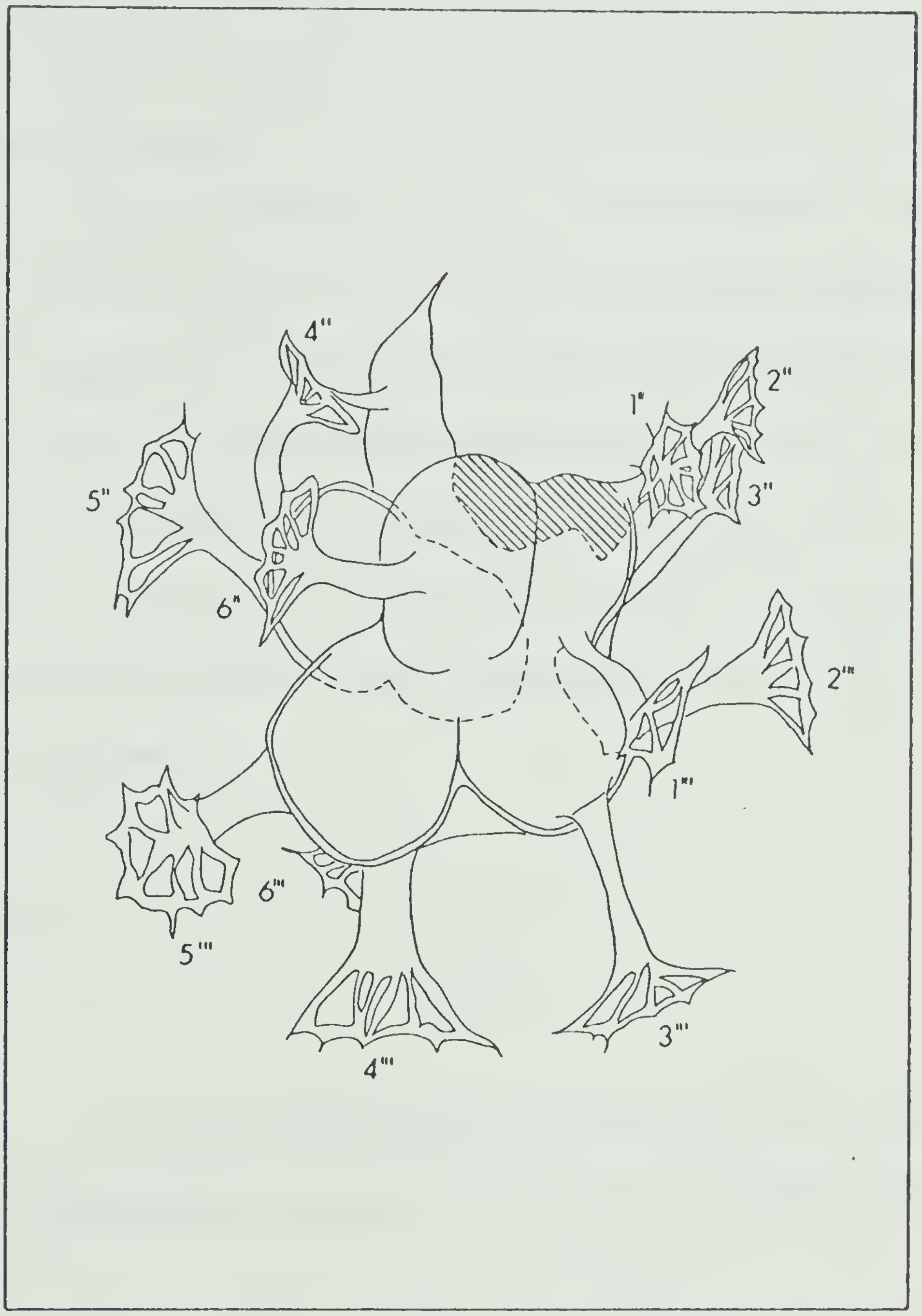

Figure 16: forma a
Semidiagrammatic sketch.
x c. 1275.

Remarks

These cysts are peculiar in the structure of the central body which appears to be made up of discrete chambers. Two whorls are present, one at either side of the cingulum. A single chamber is centrally placed on the ventral surface of the cyst and it is regarded as being equivalent to reflected plate 7''. The laevo-rotatory helicoidal cingulum apparently divides the two whorls. It is of interest to note that no antapical process is present. There is, however, a possible accessory sulcal process. Also of interest is the opening in reflected plate 2''' whose regular nature belies an accidental origin. It appears that the archeopye has been formed by partial loss of the apical plate series with a single opercular piece remaining. It was difficult to observe the exact relationship of this operculum ? to the archeopyle. Evitt (pers. comm.) considers that the lobate nature of this cyst is due to deformation possibly as the result of the growth of pyrite sphaerules. The author is not entirely convinced of this, hence the above description, however this cyst is not placed in a formalised taxon.

Affinities

Unknown.

Genus Oligosphaeridium Davey & Williams 1966b.

Type Species: Oligosphaeridium complex (White) Davey & Williams 1966b; O.D.

Remarks

This genus was erected to accommodate Hystrichosphaeridium - like cysts that lack cingular processes. The genus has a geological range of Oxfordian-Upper Oligocene.

Oligosphaeridium anthophorum (Cookson & Eisenack)

Davey 1969a

Plate V., Figure 8
Plate VI., Figure 2.

1958. Hystrichosphaeridium anthophorum Cookson & Eisenack; 43-44, pl. II, figs, 12, 13.

1969a. Oligosphaeridium anthophorum (Cookson & Eisenack) Davey; 147-148, pl.5, figs. 1-3.

Description

Chorate cyst, spheroidal to subspheroidal in shape, composed of periphragm and endophragm closely adpressed; the former making up the processes. Cyst smooth to microreticulate. The tabulation, as deduced from the intratabular processes is 6'', 6''', Ip, I''''. Processes are hollow, do not connect to the interior of the cyst, latispinous, erect, cylindrical to tapering and distally flared. The distal extremities are fenestrate but the margin is always entire. The archeopyle is apical of the $\bar{A}$ type, has a zig-zag margin and a prominent sulcal notch.

Figures Material

JW66-13-7(3) at 105.7-39.7; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 24.0(33.3)45.0 microns; length of short axis 21.0(31.8) 43.0 microns, the processes range in length from 12-34 microns. Sixteen specimens were measured, the number of specimens studied.

Remarks

These specimens compare well with those of Cookson & Eisenack (1958) except that they are smaller and the processes appear to be a little more slender. The species had a previously described geological range Oxfordian-Albian.

Affinities

This genus has an obvious gonyaulacacean tabulation and Wall & Dale (1968a) place it within the hystrichosphaeridioid lineage. No definite affinities have been demonstrated.

<u>Oligosphaeridium</u> <u>pulcherrimum</u> (Deflandre & Cookson)

Davey & Williams 1966b.

Plate VI., Figures 1, 4.

1955. <u>Hystrichosphaeridium</u> <u>pulcherrimum</u> Deflandre & Cookson; 270-271, pl. 1, fig. 8, text-figs. 21, 22.

1966b. <u>Oligosphaeridium</u> <u>pulcherrimum</u> (Deflandre & Cookson) Davey & Williams; 75-76, pl. 10, fig. 9, pl. 11, fig. 5.

Description

Chorate cyst, subspheroidal in shape, composed of periphragm and endophragm closely adpressed; the former makes up the processes. The cyst is smooth to microreticulate. Tabulation from the intratabular processes is 6'', 6''', 1p, 1''''. Processes are hollow, not connected to the interior of the cyst, latispinous, erect to curved, tapering and distally flared. The extremities of the processes bifurcate in some cases but in others they are fenestrate, secate and digitate. The archeopyle is apical of the $\bar{A}$ type with a zig-zag margin and a sulcal notch.

Figured Material

JW66-5-9(1) at 103.0-44.6; Bearpaw Formation, southern Alberta.

JW66-1-39(2) at 101.0-31.9; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 20.0(34.9)43.0 microns; length of short axis 23.0 (32.9)40.0 microns, processes range in length from 9-37 microns. Fifty specimens were measured, from a studied population of seventy-four.

Remarks

These specimens agree closely to those of Deflandre & Cookson (1955) except in size; the Bearpaw material being smaller. The geological range of this species is Valanginian-Lower Eocene.

Affinities

Gonyaulacacean with the hystrichosphaeridioid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Genus Polysphaeridium Davey & Williams 1966b.

Type Species: Polysphaeridium subtile Davey & Williams 1966b; O.D.

Remarks

This genus is characterised by the possession of a large number of hollow processes and an apical archeopyle. It has a geological range of Bathonian-Middle Miocene.

Polysphaeridium subtile Davey & Williams 1966b

Plate V., Figures 5, 7.

1966b. Polysphaeridium subtile Davey & Williams; 92, pl. II., fig. I.

Description

Chorate cyst, spheroidal to subspheroidal, composed of periphragm and endophragm closely adpressed; the former making up the processes. Test granulate. No tabulation. The processes are hollow, do not connect to the interior of the cyst, slender, erect to sinuous, cylindrical to tapering and distally bifid. The archeopyle is apical of the $\bar{A}$ type and has a zig-zag margin.

Figured Material

JW66-13-7(2) at 107.2-42.6; Bearpaw Formation, southern Alberta.

JW66-1-39(2) at 97.0-32.3; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 22.0(38.5)50.0 microns, length of short axis 30.0(35.9) 47.0 microns, processes range in length from 5-14 microns. Twenty specimens were measured, the number of specimens studied.

Remarks

These specimens compare well with those of Davey & Williams (1966b) except in the morphology of the distal tip of the processes; those of Davey & Williams (op. cit.) are more serrate. These is, however, a certain amount of variability in the Bearpaw specimens to suggest that these morphological variations may all be encompassed in the concept of this species. P. subtile has a geological range of Coniacian-Middle Miocene.

Affinities

Definite affinities have not been demonstrated for this species but it is suggested that the genus has gonyaulacacean affinities probably with the hystrichosphaeridioid lineage.

Genus Tanyosphaeridium Davey & Williams 1966b

Type Species: Tanyosphaeridium variecalamum Davey & Williams 1966b; O.D.

Remarks

This genus was erected to accommodate chorate cysts possessing an elongate central body and processes arranged in a circular manner about the central body. The genus has a geological range of Berriasian-Lower Eocene.

Tanyosphaeridium variecalamum Davey & Williams 1966b

Plate VI., Figures 3,5.

1966b. Tanyosphaeridium variecalamum Davey & Williams; 98-99, pl.6., fig. 7., text-fig. 20.

Description

Chorate cyst, elongate in shape, composed of periphragm and endophragm closely adpressed; the periphragm makes up the processes. Cyst microgranulate. A

tentative tabulation from specimens where the processes appear to be restricted to one per plate area is 6'', 6c, 6-7''', 1p, 1''''. The processes are hollow, latispinous, erect to curved, cylindrical to tapering and distally flared. The extremities are slightly recurved and denticulate. Processes are arranged one to three per plate area and may be variable per specimen. The archeopyle is apical of the $\overline{A}$ type with a sulcal notch often visible.

Figured Material

JW66-1-39(3) at 106.0-38.0; Bearpaw Formation, southern Alberta.

JW66-1-39(3) at 109.0-40.9; Bearpaw Formation, southern Alberta.

Dimensions

Length 25.0(31.4)37.0 microns, breadth 15.0(22.3)42.0 microns, length of processes ranges from 6-13 microns. Seven specimens were measured, the number of specimens studied.

Remarks

These specimens compare well in all respects to those figured by Davey & Williams (1966b). This species had a previously recorded geological range of Albian-Cenomanian.

Affinities

The possession of a single reflected antapical plate suggests a gonyaulacacean affinity for this cyst, probably with the hystrichosphaeridioid lineage.

Cyst-Family Exoshosphaeridiaceae Sarjeant & Downie emend. Davey 1969c.

Remarks

Davey (1969c) has recently emended this cyst-family to give some emphasis

to the nature of the processes, "ornamentation" and the distinct polar structures.

Genus Exochosphaeridium Davey et al. 1966

Type Species: Exochosphaeridium phragmites Davey et al. 1966; O.D.

Remarks

This genus is characterised by a single large branched apical process and a precingular archeopyle. The genus differs from Trichodinium Eisenack & Cookson (1960) in lacking a clearly differentiated cingulum. The genus has a geological range of Albian-Lower Eocene.

Exochosphaeridium cf. phragmites Davey et al. 1966

Plate VI., Figure 6.

1966. Exochosphaeridium phragmites Davey et al; 165-166, pl. 2, figs. 8-10.

Description

Chorate cyst, subspheroidal in shape, made up of periphragm and endophragm closely adpressed; the former makes up the processes. Test granulate. A large apical process is present and is one sixth to one fifth the length of the cyst, carries granules, is branched and distally acuminate. The other processes appear randomly distributed on the test and are slender, solid, tapering and distally acuminate. No tabulation was seen. The archeopyle is precingular of the P or 2P type.

Figured Material

JW66-1-39(3) at 106.0-35.5; Bearpaw Formation, southern Alberta.

Dimensions

Length 52.0(62.0)84.0 microns, breadth 43.0(50.3)63.0 microns, processes vary in length from 2-8 microns. Six specimens were measured, the number of specimens studied.

Remarks

Except in lacking the pitted nature of the central body and possessing smaller processes, the Bearpaw specimens compare favourably with those of Davey _et al_. (1966). This species had a previously recorded range of Albian-Cenomanian.

Affinities

Possibly gonyaulacacean in the apteodinioid lineage, but definite affinities are not known.

Exochosphaeridium pseudohystrichodinium
(Deflandre) emend. Davey 1969a.
Plate VI., Figure 7.

1937. _Hystrichosphaeridium pseudohystrichodinium_ Deflandre; 73, pl. 15, figs. 3,4.

1969a. _Exochosphaeridium pseudohystrichodinium_ (Deflandre) emend. Davey; 163-164, pl. 11, figs. 4, 5.

Description

Chorate cyst, subspheroidal in shape, consisting of periphragm and endophragm closely adpressed; the periphragm constructing the processes. Test granulate, fibro-pitted (Davey 1969c). The apical process is large, up to one-third the length of the cyst, is granulate and branched. Processes are solid, broad at the base, slender, erect to sinuous, cylindrical, acuminate, oblate, or bifid. On some areas of the test the processes give the appearance of being aligned. In this way a faint trace of a cingulum may be seen. No other tabulation could be discerned as the processes appear randomly distributed. The archeopyle is precingular of the P type.

Figured Material

JW66-5-5(2) at 110.0-31.7; Bearpaw Formation, southern Alberta.

Dimensions

Length 53.0(60.1)71.0 microns, breadth 44.0(53.3)69.0 microns, processes

range in length from 10-20 microns. Six specimens were measured, the number of specimens studied.

Remarks

These specimens compare well with those of Davey (1969) except for the detail of the pitted test. All specimens attributed to this species were granulate, like the previously described species. The possession of a slight cingulum in some species suggests this species should be transferred to Trichodinium Eisenack & Cookson 1960 but as this is the exception rather than the rule it is assigned as above. It may, however, prove necessary in the future to treat Exochosphaeridium as a junior synonym of Trichodinium. This species has a geological range of Cenomanian-Eocene.

Affinities

Possibly gonyaulacacean with the apteodinioid lineage.

Exochosphaeridium bifidum (Clarke & Verdier)
Clarke et al. 1968
Plate VI., Figure 9.

1967. Baltisphaeridium bifidum Clarke & Verdier; 72-73, pl. 17., figs. 5-6, text-fig. 30.

1968. Exochosphaeridium bifidum (Clarke & Verdier) Clarke et al.; 182.

Description

Chorate cyst, subspheroidal to ovoidal in shape, made up of two wall layers closely adpressed; the periphragm constructs the processes. The epitract is slightly more conical than the hypotract. Test is coarsely granulate (fibro-pitted ? of Davey 1969c), and it is of interest to note that some of the processes are granulate others are smooth. Tabulation not observed, although some alignment of the processes suggests the course of the cingulum; otherwise the processes appear randomly distributed. Processes are long, solid, slender, erect, cylindrical and distally

bifid. A single apical process may be observed, but this is not always as clear as in other members of this genus. Archeopyle not observed.

Figured Material

JW68-I-8(2) at 107.0-47.0; Bearpaw Formation, southern Alberta.

Dimensions

Length 38.0 microns, breadth 32.0 microns, processes range in length from 10-20 microns. One specimen was measured, the number of specimens studied.

Remarks

This species recently transferred to Exochosphaeridium is considered to have a precingular archeopyle; presumably in the original diagnosis the cysts were incorrectly orientated. Unfortunately the specimen described above did not exhibit an archeopyle. The lack of a conspicuous branched apical process gives a certain amount of doubt to the generic assignment, but future work should clarify these doubts. The geological range for this species is Cenomanian-Campanian.

Affinities

Possibly gonyaulacacean with the apteodinioid lineage.

Exochosphaeridium sp. A

Plate VI., Figure 8.

Description

Chorate cyst, subspheroidal in shape, made up of periphragm and endophragm closely adpressed; the former making up the processes. Test smooth. The apical process is large, up to one-fifth of the cyst length and is branched. The processes are solid to membraneous, cylindrical, erect to curved and distally oblate to bifurcate. In plan the membraneous processes give a reticulate pattern to the cyst surface. Tabulation was not observed nor was the archeopyle.

Figured Material

JW68-1-2(1) at 101.0-33.6; Bearpaw Formation, southern Alberta.

Dimensions

Length 50.0(62.8)98.0 microns, breadth 43.0(49.8)60.0 microns, processes range in length from 5-10 microns. Five specimens were measured, the number of specimens studied.

Remarks

These specimens are unlike all other previously described species of Exochosphaeridium but the scarcity of specimens precludes the erection of a new species. The distinguishing feature is the apparent reticulate pattern on the cyst surface.

Affinities

Possibly gonyaulacacean with the apteodinioid lineage.

Cyst-Family Areoligeraceae Evitt emend. Sarjeant & Downie 1966

Genus Cyclonephelium Deflandre & Cookson emend. Cookson & Eisenack 1962.

Type Species: Cyclonephelium compactum Deflandre & Cookson 1955; O.D.

Remarks

The original diagnosis of this genus was emended by Cookson & Eisenack (1962) and later by Williams & Downie (1966) to correct the interpretation of cyst orientation and to fully describe the range of process structure. The later emendation of Williams & Downie (1966) is nearly word for word the same as that of Cookson & Eisenack (op.cit.). The genus has a geological range of Oxfordian-Oligocene. Davey (1969a) suggested that the genus had a preference for open marine conditions.

<u>Cyclonephelium distinctum</u> Deflandre &
Cookson 1955
Plate VII., Figures 1, 2.

1955. <u>Cyclonephelium distinctum</u> Deflandre & Cookson; 285-286, pl. 2, fig. 14, text-figs. 47-48.

Description

Chorate cyst, subspheroidal in shape, usually appearing as a hemisphere, the operculum is usually lost. The cyst is constructed of a single wall layer or two wall layers closely adpressed. A small apical horn and two antapical horns are also present. The cyst is smooth to microgranulate. The processes are only developed along the peripheral portion of the cyst as seen in dorso-ventral view, leaving "bald" areas on both the ventral and dorsal surfaces. Processes are short, slender, erect to curved, cylindrical, tapering to buccinate, distally bifurcate, closed and open and sometimes flared. The archeopyle is apical of the $\bar{A}$ type.

Figured Material

JW66-10-5(1) at 97.0-43.3; Bearpaw Formation, southern Alberta.

JW66-9-3(1) at 108.0-34.6; Bearpaw Formation, southern Alberta.

Dimensions

Length 37.0(48.9)84.0 microns; breadth 39.0(51.9)87.0 microns, processes range in length from 2-18 microns. Thirty eight specimens were measured, the number of specimens studied.

Remarks

This species is recorded for the first time from Campanian rocks. A large degree of process variation is observed for this species. <u>C. distinctum</u> is characterised by the isolated nature of the process. <u>C. compactum</u> Deflandre & Cookson 1955 is very similar except the processes are lamella-like.

Affinities

No definite affinities have been demonstrated but Wall & Dale (1968a)

consider it to be gonyaulacacean with the areoligeroid lineage.

Cyclonephelium cf. paucispinum Davey 1969

Plate VII., Figure 4.

1969 ?Cyclonephelium paucispinum Davey; 170, pl. 9, figs. 1, 2.

Description

Chorate cyst, sub-polygonal in shape, consisting one wall layer or of two wall layers closely adpressed. Test is smooth to microgranulate with no trace of a tabulation. Two antapical horns are present one of which is much larger than the other. The processes are circumferentially developed and the processes are scarce as compared to other species of the genus. Processes are short, slender, erect to curved, distally acuminate, flared, bifurcate, tapering to buccinate. Archeopyle apical of the $\bar{A}$ type.

Figured Material

JW66-10-5(1) at 103.0-40.5; Bearpaw Formation, southern Alberta.

Dimensions

Length 58.0 microns; breadth 56.0 microns; processes range in length from 3-7 microns. One specimen was measured, the number of specimens studied.

Remarks

This species is characterised by its scarcity of processes. It had previously only been recorded from the Cenomanian (Davey 1969). Evitt (pers.comm.) thinks that this specimen may be a variant of C. distinctum. Whilst this is possible the writer did not observe any transitional specimens between C. distinctum and the above specimen and so prefers to compare it directly with C. paucispinum. It would not be wise to extend the range of this species, however, on this evidence alone.

Affinities

Definite affinities not known but it is possibly gonyaulacacean with areoligeroid lineage (Wall & Dale 1968a).

Cyst-Family Spiniferitaceae cyst-fam. nov. = Cyst-Family Hystrichosphaeraceae Wetzel emend. Sarjeant & Downie 1966.

Genus Spiniferites Mantell ex Loeblich & Loeblich 1966

Type Species: Spiniferites ramosus (Ehrenberg) Mantell 1854; S.D.

Remarks

This genus was not formally typified until 1966 when Loeblich & Loeblich designated Xanthidium ramosum Ehrenberg 1838 as type species. Sarjeant (1964), however, had argued that because Spiniferites was no longer in common usage and had not been validated by typification the generic names Hystrichosphaera and Hystrichosphaeridium should be conserved. Loeblich and Tappan (1967) pointed out the subsequent typification of the genus by Loeblich & Loeblich (op. cit.) and argued that Spiniferites is a valid genus and a senior synonym to Hystrichosphaera such that the latter genus should be denied conservation. The authors also point out that with such typification the genus Hystrichosphaeridium is not subsequently in need of conservation. Loeblich (pers. comm.) has convinced the General Committee for Botanical Nomenclature of his views, hence the use of the name Spiniferites here, and the use in Wall & Dale (1970). The genus has a geological range of Oxfordian-Holocene.

Spiniferites cornutus (Gerlach) comb. nov.

var. A

Plate VII., Figure 6.

1961. Hystrichosphaera cornuta Gerlach; 180, pl. 27, figs. 10-12.

Description

Proximo-chorate cyst, subspheroidal to ovoidal in shape with a slight apical boss. The cyst is composed of two closely adpressed wall layers. Processes

are made up of the periphragm. A slight separation of the wall layers takes place at the apex. Test is smooth or microgranulate. Tabulation is clearly decipherable, the fields being separated by upraised sutures, as 4', 6''; plate 6'' being triangular, 6c, 5-6''', lp, l''''. Processes are all gonal. The apical process is very long and conspicuous, taeniate, erect, branched and distally bifurcate. One of the bifurcations is bifid. The branch appears orthogonal, multifurcate, recurved, the ultimate branches are long and slender. The other processes are slender to latispinous, erect to curved, distally orthogonal and recurved. No archeopyle was seen.

Figured Material

JW66-12-28(3) at 110.9-47.2; Bearpaw Formation, southern Alberta.

Dimensions

Length 42.0 microns; breadth 30.0 microns, processes range in length from 8-12 microns, with the apical process 18 microns tall. One specimen was measured, the number of specimens studied.

Remarks

This specimen belongs to the species Spiniferites cornutus Gerlach by virtue of the possession of a large prominent apical process. It is different, in possessing orthogonal, recurved gonal processes, from all other varieties of this species, but because of the scarcity of specimens this particular variety can only be designated as variety A. The previous range of this species was Lower Eocene-Middle Miocene.

Affinities

Wall (1965) and Wall & Dale (1967, 1968a) have clearly demonstrated the affinity of this genus with the modern genus Gonyaulax Diesing 1866; they place it, therefore with the gonyaulacoid lineage.

Spiniferites ramosus var. multibrevis (Davey & Williams) comb. nov.

Plate VII., Figure 9.

1966a. Hystrichosphaera ramosa var. multibrevis, Davey & Williams; 35-37, pl. 1, fig. 4, pl. 4, fig. 6, text-fig. 9.

Description

Proximochorate cyst, spheroidal to ovoidal in shape. Test made up of periphragm and endophragm closely adpressed. Periphragm makes up the processes. Cyst is smooth or microgranulate. The epitract tends to be a little rectangular in contract to the hypotract which is hemispheroidal. The tabulation is typical for the genus; the plate areas are delimited by sutural ridges which often extend into crests. The crests often contribute to the processes. The cingulum is four to five microns in width and takes the form of a laevo-rotatory helicoid. It is displaced by three times its own width. Processes are short, solid, slender, erect to curved, tapering, with a multifurcate extremity, each branch with a distal bifid tip; both gonal and sutural processes are present. The processes appear to have a central solid core which carries the sutural crests. The archeopyle was not observed.

Figured Specimen

JW66-5-1(1) at 103.0-32.4; Bearpaw Formation, southern Alberta.

Dimensions

Length 20.0(33.9)42.0 microns; breadth 18.0(26.75)35.0 microns, processes range in length from 3-12 microns. Twenty two specimens were measured, the number of specimens studied.

Remarks

This variety, easily recognised in the Bearpaw assemblages, compares well with those figured by Davey & Williams (1966a). It is characterised by its short gonal and sutural processes; it has a geological range from Hauterivian-Eocene.

Affinities

Gonyaulacacean with the gonyaulacoid lineage (Wall & Dale 1968a).

Spiniferites ramosus var. granosus (Davey & Williams) comb. nov.

Plate VII., Figure 7.

1966a. Hystrichosphaera ramosa var. granosa Davey & Williams; 35, pl. 4, fig. 9.

Description

Proximo-chorate cyst, ovoidal in shape, made up of periphragm and endophragm closely adpressed. The periphragm makes up the processes and is coarsely granulate. The tabulation can only be seen in certain areas of the cyst where the fields are delimited by raised sutures that carry large crests. The cingulum and sulcus are indistinct. Processes are slender to taeniate, erect, tapering to subconical, bifurcating or trifurcating with bifid distal extremities. The archeopyle was not observed.

Figured Material

RH69-13-3(3) at 96.8-53.3; Bearpaw Formation, southern Alberta.

Dimensions

Length 39.0(43.25)46.0 microns; breadth 32.0(34.5)38.0 microns, processes range in length from 9-19 microns. Five specimens were measured, the number of specimens studied.

Remarks

These specimens compare well with those of Davey & Williams (1966a) except in differences of process morphology probably due to specific variability. This variety previously had been recorded only from the Eocene.

Affinities

Gonyaulacacean with the gonyaulacoid lineage (Wall & Dale 1968a).

Spiniferites cf. porosus (Manum & Cookson) comb. nov.

Plate VII., Figure 8.

1964. Hystrichosphaera porosa Manum & Cookson; 11-12, pl.2, figs. 1-5, text-fig.2.

Description

Proximo-chorate cyst, spheroidal to ovoidal in shape, made up of periphragm and endophragm closely adpressed. The endophragm may be thickened; the periphragm makes up the processes. Cyst smooth. Tabulation is present with the field delimited by sutural ridges; no specimen, however, was seen in which the tabulation could be deciphered. Processes are hollow, latispinous, erect, buccinate, open distally, fenestrate and digitate. One or two specimens were observed in which cylindrical sutural processes were present. Archeopyle precingular of type P, formed by the loss of plate 3''.

Figured Material

JW66-13-10(2) at 109.4-44.8; Bearpaw Formation, southern Alberta.

Dimensions

Length 33.0(38.8)46.0 microns; breadth 22.0(32.5)40.0 microns, processes range in length from 8-18 microns. Seventeen specimens were measured, the number of specimens studied.

Remarks

This species is morphologically similar to H. porosa Manum & Cookson but in certain specimens a similarity with H. perforata Davey & Williams 1966 was apparent. It may be that there is a complete morphological range between these two species. H. porosa had a recorded geological range of Aptian-Turonian.

Affinities

Gonyaulacacean with the gonyaulacoid lineage (Wall & Dale 1968a).

Spiniferites ramosus var. gracilis

(Davey & Williams) comb. nov.

Plate VII., Figure 3.

1966a. Hystrichosphaera ramosa var. gracilis Davey & Williams; 34-35, pl. 1, fig. 5, pl. 5, fig. 6.

Description

Proximo-chorate cyst, spheroidal to ovoidal in shape, made up of periphragm and endophragm closely adpressed. The periphragm makes up the processes. Test smooth to microgranulate. Tabulation typical for the genus, the plates delimited by sutural ridges. The cingulum is conspicuous and takes the form of a laevo-rotatory helicoid with a displacement approximately equal to one half the width of the cingulum. Processes are slender, possibly solid, erect, cylindrical to tapering, distally trifurcate with the exception of the sutural processes which are bifurcate. All processes are distally bifid. Some specimens have a large antapical membranous suture connecting two conspicuous antapical processes. Archeopyle was not observed.

Figured Material

RH69-13-3(1) at 94.0-47.3; Bearpaw Formation, southern Alberta.

Dimensions

Length 28.0(34.5)49.0 microns; breadth 21.0(30.5)38.0 microns, processes range in length from 7-18 microns. Thirteen specimens were measured, the number of specimens studied.

Remarks

These specimens compare well with those of Davey & Williams (1966a) except that in the Bearpaw assemblages there is more variability in process length; this may be an indication of a morphological trend from the ramosus type to the gracilis type. The geological range of this variety is Cenomanian-Miocene.

Affinities

Gonyaulacacean with the gonyaulacoid lineage (Wall & Dale 1968a).

Spiniferites ramosus var. membranaceus (Rossignol) comb. nov.

Plate VII., Figure 10.

1964. Hystrichosphaera furcata var. membranacea Rossignol; 86, pl. I, figs, 4, 9, 10, pl. 3, figs. 7, 12.

1966a. Hystrichosphaera ramosa var. membranacea (Rossignol) Davey & Williams; 37 pl. 4, figs. 8, 12.

Description

Proximo-chorate cyst, spheroidal to ovoidal in shape, test comprised of periphragm and endophragm closely adpressed, the former making up the processes. Cyst smooth. The tabulation is delimited by sutures that carry large membranous crests but because of folding it could not be deciphered. The cingulum is usually present but somewhat abscured by the membranous sutural crests. Processes are taeniate, erect, distally bifurcate, or multifurcate, with a bifid tip. Many of the processes are connected by the membranous sutures. The archeopyle was not observed.

Figured Material

JW66-5-1(I) at 96.0-29.3; Bearpaw Formation, southern Alberta.

Dimensions

Length 30.0(35.6)40.0 microns; breadth 22.0(27.8)38.0 microns, processes range in length from 8-18 microns. Ten specimens were measured, the number of specimens studied.

Remarks

These specimens compare well with those of Davey & Williams (1966a) but differ from those of Rossignol (1964) in lacking the two large dorsal antapical processes. In the Bearpaw assemblages this variety is, however, easily recognised. S. ramosus var. membranaceus had a previously recorded geological range of Eocene-Recent.

Affinities

Gonyaulacacean with the gonyaulacoid lineage (Wall & Dale 1968a).

Spiniferites ramosus var. ramosus

(Davey & Williams) comb. nov.

Plate VII., Figure II.

1966a. Hystrichosphaera ramosa var. ramosa Davey & Williams; 33-34, pl. I, figs. I, 6, pl.3, fig. I, text-fig. 8.

Description

Proximo-chorate cyst, spheroidal to ovoidal in shape, made up of a periphragm and endophragm closely adpressed; the former makes up the processes. Test is smooth. The tabulation is outlined by raised sutural lines and is typical for the genus. The cingulum is conspicuous, three to five microns wide, takes the form of a laevo-rotatory helicoid and is displaced by one half of the width of the cingulum. Gonal and sutural processes are present but the former are more common, they are slender, triangular, erect to curved, distally trifurcate with bifid or trifid tips. Lists from the sutures add to the process structure. The archeopyle was not observed.

Figured Material

JW66-I-39(I) at 99.0-38.2; Bearpaw Formation, southern Alberta.

Dimensions

Length 33.0(39.2)46.0 microns; breadth 22.0(30.3)35.0 microns, processes range in length from 6-18 microns. Thirteen specimens were measured, the number of specimens studied.

Remarks

This variety has a known geological range of Middle Barremian-Ypresian.

Affinities

Gonyaulacacean with the gonyaulacoid lineage (Wall & Dale 1968a).

Genus Achomosphaera Evitt 1963

Type species: Achomosphaera ramulifera (Deflandre)Evitt 1963; O.D.

Remarks

This genus is very similar in appearance to that of Spiniferites Mantell 1850 = Hystrichosphaera Wetzel ex Deflandre emend. Davey & Williams 1966a, but it is characterised by a lack of sutural ridges. Davey & Williams (1966a), however, reported that faint lines, delimiting plate boundaries, could be seen on one of the paratypes. These were not observed on the holotype but have also been noted on other forms attributed to this genus. Harland (1969) observed the presence of transitional specimens between the genera Hystrichosphaera and Achomosphaera in a Quaternary microplankton assemblage. It is clear, in the author's opinion, from the above discussion that Achomosphaera should be regarded as a particular morphological variant within the "Hystrichosphaera complex".

Achomosphaera cf. hyperacantha (Deflandre & Cookson) Davey et al. 1969
Plate VIII., Figure 2.

1955. Hystrichosphaera hyperacantha Deflandre & Cookson; 264-265, pl. 6, fig. 7.
1967. Hystrichosphaera hyperacantha Deflandre & Cookson; Wall; 100, pl. 14, fig.3.
1969. Achomosphaera hyperacantha (Deflandre & Cookson) Davey et al. 4.

Description

Proximo-chorate cyst, spheroidal to ovoidal, consisting of two closely adpressed wall layers. The cyst surface is smooth. The periphragm alone makes up the hollow processes, which do not connect to the interior of the cyst. They are slender and taeniate, erect, cylindrical to tapering; generally trifurcate with bifid tips. The processes are, like the test, smooth. Sutural ridges are absent in general although one or two faint lines may be seen in some specimens. Archeopyle not observed.

Figured Material.

JW66-10-13(2) at 94.0-32.6; Bearpaw Formation, southern Alberta.

Dimensions

Length 37.0(38.0)39.0 microns; breadth 32.0(32.5)33.0 microns. Length of processes 6-15 microns. Two specimens were measured, the number of specimens studied.

Remarks

This species has recently been formally transferred to the genus Achomosphaera by Davey et al. (1969). The observed specimens were smaller than the original specimens of Deflandre & Cookson (1955). Wall (1967) considers this species as being a robust variety of H. furcata (Ehrenberg) Wetzel. It is, however, probably best regarded as a morphotype within the "Hystrichosphaera complex". Achomosphaera hyperacantha has a recorded geological range of Lower Miocene? - Holocene. The geological range should only be extended with some reserve on the evidence of only two specimens. It is characterised, in particular, by the nature of its trifurcate processes.

Affinities

It is almost certainly a gonyaulacacean dinoflagellate; Wall & Dale (1968a) consider it to be part of the gonyaulacoid lineage. No definite affinities have been demonstrated.

Cyst-Family Deflandreaceae Eisenack emend. Sarjeant & Downie 1966.

Genus Deflandrea Eisenack emend. Williams & Downie 1966

Type Species: Deflandrea phosphoritica Eisenack 1938; O.D.

Remarks

The genus, originally erected in 1938 by Eisenack, was emended by Williams

& Downie (1966) to note, in particular, the peridiniacean tabulation. Williams & Downie (op. cit.) state that this genus is represented by many species that clearly overlap with regard to their morphology. It is probably best to regard this genus as embracing a complex of morphotypes that show geographical and evolutionary intergradation; but at any one level in the stratigraphic column, a number of morphotypes may be recognised. The species described below are regarded in this light. Vozzhennikova (1967) created two new genera, Chatangiella and Australiella, and emended the genus Deflandrea in her treatment of Deflandrea-like cysts. The present author is reluctant to follow this scheme at the present time. The geological range of this genus is Hauterivian-Upper Oligocene.

Deflandrea spectabilis Alberti 1959
Plate VIII., Figures 7, 9.
Plate X., Figure 3.

1959. Deflandrea spectabilis Alberti; 99, pl. 9. figs. 7, 8.

Description

Cavate cyst, elongate in shape with the epitract conical to bell-shaped. The two wall layers are closely adpressed in the cingular region with a single large pericoel developed in the apical and antapical regions. The epitract carries a single antapical horn which may be distally rounded or notched. The hypotract carried two antapical horns, one of which is larger than the other, and often distally acuminate. The endoblast is conspicuous and one third to a half the total length of the cyst. The cingulum and sulcus are usually present together with certain indications of further tabulation. The cingulum has very little displacement. Particular tabulation patterns, however, could not be recognised. The archeopyle is intercalary of the I type and is rounded hexagonal in shape, with some lateral elongation (Plate X., Figure 3). No archeopyle was seen in the endoblast and in

some specimens the operculum was lying in the pericoel.

Figured Material

JW68-2-1(3) at 103.0-44.3; Bearpaw Formation, southern Alberta.

JW66-5-1(1) at 95.0-35.9; Bearpaw Formation, southern Alberta.

Dimensions

Length 58.0(65.5)87.0 microns; breadth 32.0(41.7)50.0 microns. Fifty specimens were measured, out of a studied population of seventy-four.

Remarks

This species is common in the Bearpaw Formation, it has a large specific variation as interpreted from the assemblages studied and it is not difficult to visualise that with more of a conical epitract it would appear very similar to *D. cooksoni* as figured by Clarke & Verdier (1967); but with a bell shaped epitract it is closer to the holotype of *D. cooksoni*. Vozzhennikova (1967) regards this species as a member of the genus *Australiella*. *D. spectabilis* has a geological range of Santonian-Campanian.

Affinities

Manum (1963) reported a peridiniacean tabulation for certain species of *Deflandrea*, and Wall & Dale (1968a) place it in the deflandreoid lineage.

Deflandrea korojonensis Cookson &
Eisenack 1958
Plate VIII., Figure 8.
Plate X., Figure 4.

1958. *Deflandrea korojonesis* Cookson & Eisenack; 27, Pl. 4, figs. 10, 11.

Description

Cavate cyst, elongate to fusiform, consisting of two wall layers closely adpressed only in the cingular region. Pericoels are developed at the apex and antapex. The epitract is always somewhat conical. A single apical horn is present

generally short and distally rounded; two antapical horns may be present but it is more usual to find the antapex area flat. The endoblast, which is very conspicuous, is approximately half the length of the cyst. There is no tract of any tabulation and the archeopyle, invariably present, is intercalary of the I type, rounded polygonal in shape, with a conspicuous straight edge towards the antapex (Plate X., Figure 4). No archeopyle was observed in the endoblast.

Figured Material.

JW66-10-5(I) at 93.0-44.2; Bearpaw Formation, southern Alberta.

Dimensions

Length 70.0(97.4)132.0 microns; breadth 40.0(56.6)82.0 microns. Thirteen specimens were measured, the number of specimens studied.

Remarks

This species may be distinguished from D. spectabilis by its overall shape and by the absence of any type of tabulation. It forms a distinct morphotype within these assemblages. It is, however, close to D. bakeri, Deflandre & Cookson 1955, the major difference being the nature of "ornamentation"; D. bakeri having a punctate test. Vozzhennikova (1967) regards this species as a member of the genus Australiella. D. korojonensis has a geological range of Campanian - Maastrichtian.

Affinities

Peridiniacean with the deflandreoid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Deflandrea echinoidea Cookson & Eisenack 1960

Plate VIII., Figure 3.

1960. Deflandrea echinoidea Cookson & Eisenack; 2, pl. I., figs. 5, 6.

Description

Cavate cyst, sub-polygonal to elongate, composed of two wall layers closely adpressed in the cingular region, elsewhere forming pericoels. Epitract is conical

to slightly bell shaped and carries a single short apical horn. The hypotract carries two antapical horns, one of which is larger than the other. The cyst carries numerous large granules which are sometimes elongate and acuminate. These appear scattered at random on the cyst test and are constructed of periphragm. The endocorpus is generally inconspicuous but is one third to a half the length of the cyst. The cingulum and sulcus may be observed but are usually indistinct. The archeopyle was not observed.

Figured Material

JW66-5-7(2) at 102.0-47.7; Bearpaw Formation, southern Alberta.

Dimensions

Length 60.0(67.0)71.0 microns; breadth 45.0(48.3)50.0 microns. Two specimens were measured, the number of specimens studied.

Remarks

This species forms a distinct morphotype within the Bearpaw Formation by virtue of its "ornamentation", but it is otherwise morphologically similar to _D. spectabilis._ _D. echinoidea_ has a geological range of Albian - Campanian.

Affinities

Peridiniacean with the deflandreoid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Deflandrea granulifera Manum 1963

Plate VIII., Figure I.

Plate X., Figure 5.

1963. _Deflandrea granulifera_ Manum; 61-64 pl. 3, figs. 5-9.

Description

Cavate cyst, elongate in form, with a pronounced bell shaped epitract. Two wall layers, closely adpressed only at the cingulum, are elsewhere separated by

pericoels. Both layers are granulate to microgranulate. One apical horn is present which is distally rounded and may in addition be notched. The hypotract carries two antapical horns, one of which is more pronounced than the other. The endoblast is prominent and is a half to two thirds the length of the cyst. Certain splits on the dorsal surface of the epitract suggest the presence of one or two apical plates. The complete tabulation is not evident but the cingulum and sulcus are conspicuous. The cingulum is marked by a number of sutures, but they are not complete so that six cingular plates are indicated. The bell-shaped epitract is possibly constructed largely of intercalary plates. The archeopyle is intercalary of the I type and is large and founded polygonal in shape. The endoblast has a 3I archeopyle (Plate X., Figure 5.).

Figured Material

JW66-I-37(3) at 100.0-39.2; Bearpaw Formation, southern Alberta.

Dimensions

Length 100.0 microns; breadth 59.0 microns. One specimen was measured, the number of specimens studied.

Remarks

This specimen is very similar to the holotype of the species D. victoriensis as figured by Cookson & Manum (1964). Cookson & Manum (op.cit.) point out that the two species differ in "ornamentation", in the sizes of the apical horn and in the proportion of the apical horn to the overall size. It is important to note, however, that D. granulifera has a 3I endoblastic archeopyle. Vozzhennikova (1967) regards this species as a member of the genus Australiella. D. granulifera has a geological range of Albian-Turonian. It is not considered that this range should be increased on the evidence of one specimen.

Affinities

Peridiniacean with the deflandreoid lineage (Wall & Dale 1968a). No

definite affinities have been demonstrated.

Deflandrea tripartita Cookson & Eisenack emend.
Cookson & Manum 1964
Plate VIII., Figure 6.
Plate X., Figure 6.

1960. *Deflandrea tripartita* Cookson & Eisenack; 2, pl. I., fig. 10.

Description

Cavate cyst, elongate with a pronounced bell shaped epitract. Two wall layers are present, closely adpressed only in the cingular region, elsewhere they are separated by a pericoel. There is a single apical horn and two antapical horns. The apical horn is distally rounded whereas the antapical horns are more acuminate with one being longer than the other. Test is smooth to microgranulate. There is no trace of the tabulation, not even a cingulum or sulcus, and the archeopyle is intercalary of the I type, elongate trapezium to rounded polygonal in shape. No archeopyle was seen in the endoblast.

Figured Material

JW66-14-13(2) at 107.8-30.9; Bearpaw Formation, southern Alberta.

Dimensions

Length 75.0(94.0)105.0 microns; breadth 35.0(48.6)62.0 microns. Six specimens were measured, the number of specimens studied.

Remarks

This species is similar to *D. victoriensis* but differs in that it lacks all traces of tabulation. A full discussion of these and related species may be found in Cookson & Manum (1964). Vozzhennikova (1967) regards this species as a member of the genus *Australiella*. *D. tripartita* has a geological range of Turonian - Campanian.

Affinities

Peridiniacean with the deflandreoid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Deflandrea macrocysta Cookson & Eisenack 1960

Plate VIII., Figure 5.

1960. Deflandrea macrocysta Cookson & Eisenack; 3, pl. I., figs 7-8

Description

Cavate cyst, ovoidal to elongate, made up of two wall layers closely adpressed in the cingular region, elsewhere separated to form pericoels. The pericoels are, however, somewhat restricted as the endoblast occupies three quarters of the length of the cyst. The endophragm is thick, up to two microns. The epitract carries a single apical horn which is distally rounded; the hypotract carries two distally rounded antapical horns of equal length. The test is microgranulate. No tabulation was observed except for a slight indication of a cingulum in some specimens. Folding is present in the thin periphragm. Archeopyle not observed.

Figured Material

JW66-12-13(2) at 99.2-39.0; Bearpaw Formation, southern Alberta.

Dimensions

Length 44.0(67.6)78.0 microns; breadth 36.0(47.6)54.0 microns. Ten specimens were measured, the number of specimens studied.

Remarks

This species forms a distinct morphological type in Bearpaw assemblages. In general form it appears quite close to Trithyrodinium evittii Drugg 1967 but differs in possessing an intercalary archeopyle formed by the loss of a single plate.

Affinities

Peridiniacean with the deflandreoid lineage (Wall & Dale 1968a). No definite affinities have been demonstrated.

Deflandrea sp.

Plate VIII., Figures 4, 10.

Description

Cavate cyst, elongate to peridinoid; epitract markedly conical, hypotract hemi-spheroidal. Cyst made of two wall layers closely adpressed only in the equatorial region. A large apical pericoel is present but an antapical pericoel as such is not present, two small pericoels are present, however, one developed at each of the two antapical horns. The periphragm is smooth to microgranulate; the endophragm is thick (one micron) and appears scabrate. The endoblast extends for three quarters the length of the cyst. Tabulation is lacking but a poorly defined cingulum may be observed. The apical horn is long and rounded distally, the antapical horns are acuminate in one case, and rounded distally in the other. A notable characteristic is the large swollen base of one of the antapical processes. Archeopyle not observed in either the periblast or endoblast.

Figured Material

JW66-12-28(1) at 93.0-44.6; Bearpaw Formation, southern Alberta.

Dimensions

Length 70.0 microns; breadth 41.0 microns, one specimen was measured, the number of specimens studied.

Remarks

This form is distinguished by possessing a markedly conical epitract, dark conspicuous endocorpus and a swollen base to one of the antapical processes. The paucity of specimens precludes description as a new species. It is possible that the swollen base to one of the antapical processes is the result of deformation due to the growth of a ?pyrite sphaerule.

Affinities

Peridiniacean with the deflandreoid lineage (Wall & Dale 1968a). Definite affinities have not been demonstrated.

Cyst-Family Hexagoniferaceae Sarjeant & Downie 1966

Genus Hexagonifera Cookson & Eisenack emend. Cookson & Eisenack 1962.

Type Species: Hexagonifera glabra Cookson & Eisenack 1961; O.D.

Remarks

This genus was emended in 1962 by its original authors to attribute greater importance to the outer "membrane". The geological range of this genus is Albian-Campanian.

Hexagonifera chlamydata Cookson & Eisenack 1962

Plate VIII., Figure II.

1962. Hexagonifera chlamydata Cookson & Eisenack; 496, pl. 7., figs. 1-3, 5-8.

Description

Cavate cyst, ovoidal in shape, with two wall layers closely adpressed only in the cingular region. The endophragm carries a dense microgranulation whereas the periphragm has a less conspicuous microgranulation. The tabulation is poorly seen except on the epitract where at least six precingular plates may be observed. Cingulum and sulcus are not present. Archeopyle apical, possibly of the $\overline{AI}$ type, formed by loss of the apical plate series together with some anterior intercalary plates.

Figured Material

JW66-13-13(I) at 112.4-33.0; Bearpaw Formation, southern Alberta.

Dimensions

Overall length 59.0 microns; breadth 56.0 microns; length of endoblast 51.0 microns; breadth 52.0 microns. One specimen was measured, the number of

specimens studied.

Remarks

The similar structure of the $\overline{AT}$ archeopyle to that of the genus Ascodinium might indicate a possible relationship. H. chlamydata had a recorded range of Albian-Cenomanian so that this observation greatly extends its range. It is unwise, however, to do so on the evidence of one specimen. The species is characterised by its "ornamentation' and the prominence of the periphragm; it differs from H. suspecta Manum & Cookson 1964 in lacking antapical horns.

Affinities

Definite affinities unknown. Wall & Dale (1968a) place this genus, together with Ascodinium, with the deflandreoid lineage of the Peridiniaceae.

Cyst-Family Pseudoceratiaceae Eisenack emend. Sarjeant & Downie 1966

Genus Odontochitina Deflandre 1935

Type Species: Odontochitina operculata (Wetzel) Deflandre 1946 = Odontochitina silicorum Deflandre 1935; O.D.

Remarks

This genus, erected in 1935 by Deflandre, had O. silicorum designated as type species. This species, however, was a junior synonym of Ceratium (Euceratium) operculatum Wetzel 1933. Deflandre (1946) was the first to recombine Ceratium operculatum. The genus has a geological range of Hauterivian-Maestrichtian.

Odontochitina operculata (Wetzel) Deflandre 1946

Plate IX., Figure I.

1933 Ceratium (Euceratium) operculatum Wetzel; 170 pl. 2, figs. 21, 22.

1946 Odontochitina operculata (Wetzel) : Deflandre; 238, figs. 1016 - 1019.

1952 Odontochitina operculata (Wetzel) : Firtion; 160, pl. 9, fig. 9.

Description

Cyst, triangular in shape, composed of endophragm and periphragm; the latter making up the horns. The test may be smooth, granulate or porate. The epitract carries a single large apical horn, that may also be smooth, granulate or porate; it is hollow, latispinous, tapering and distally oblate or evexate. The two antapical horns are shorter than the apical horn but are of the same general character. No tabulation was observed. The archeopyle is possibly apical in nature or it could be a combination type involving apical and intercalary plate equivalents.

Figured Material

JW66-1-39(2) at 99.0-32.9; Bearpaw Formation, southern Alberta.

Dimensions

Endoblast: length of long axis 42.0(53.9)71.0 microns, length of short axis 39.0(49.9)68.0 microns. The horns range in length from 54.0-200.0 microns. Thirty-one specimens were measured, the number of specimens studied.

Remarks

This was the only species of Odontochitina observed in the Bearpaw assemblages. It is distinguished from O. costata Alberti emend. Clarke & Verdier, which in many respects it closely resembles, by lack of striations on the horns. It is uncertain whether the horns of Odontochitina are equivalent to horns as seen in many modern species of Ceratium or whether they should be more correctly termed processes.

Affinities

Unknown

Incertae Sedis

Group Acritarcha Evitt 1963.

Subgroup Acanthomorphitae Downie *et al*. 1963

Genus *Baltisphaeridium* Eisenack emend. Downie & Sarjeant 1963.

Type Species: *Baltisphaeridium longispinosum* (Eisenack) Eisenack 1958; O.D.

Remarks

Together with *Micrhystridium* this genus is characterised on a size criterion, in that the mean and mode for the diameter of the central body must be greater than twenty microns. The genus has a geological range of Precambrian-Recent.

Baltisphaeridium sp. A

Plate IX., Figure 5.

Description

Cyst subspheroidal, made up of a single wall layer. Test smooth. Processes are numerous, connect to the interior of the cyst, hollow, latispinous, erect to curved, strongly tapering, and terminating in a small bifid tip. A pylome was not observed.

Figured Material

JW66-5-9(1) at 105.0-38.0; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 15.0(25.3)33.0 microns; length of short axis 15.0(21.5) 32.0 microns; processes range in length from 3-31 microns. Thirty-one specimens were measured, the number of specimens studied.

Remarks

This species, placed in Baltisphaeridium because of its size, is characterised by the many, markedly tapering hollow processes that possess a bifid tip.

Affinities

Possibly gymnodinialean ?

Genus Micrhystridium Deflandre emend.

Downie & Sarjeant 1963.

Type Species: Micrhystridium inconspicuum (Deflandre) Deflandre 1937; O.D.

Remarks

This genus is the subject of much controversy in that a figure of twenty microns was quoted by Downie & Sarjeant (1963) as the maximum figure for the mean and mode of the central body of these cysts. Many people would insist that this is unrealistic. Staplin (1961) diagnoses the genus as possessing hollow spines that are distally closed but connect to the interior of the cyst. In the present assemblages the generic diagnosis of Downie & Sarjeant (op.cit.) is used. Future research will in all probability clear up many of the doubts associated with acritarch taxonomy.

Micrhystridium sp. A

Plate IX., Figures 2, 3.

Description

Cyst subspheroidal, composed of a possible single wall layer, scabrate. The processes are few in number, long, solid, slender, cylindrical, erect to curved

and distally acuminate. A pylome was not observed.

Figured Material

JW69-1-1(1) at 93.0-45.4; Bearpaw Formation, southern Alberta.

JW66-13-13(2) at 108.0-35.6; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 16.0(21.2)35.0 microns, length of short axis 10.0(16.8) 23.0 microns, the processes range in length from 8-30 microns. Twenty three specimens were measured, the number of specimens studied.

Remarks

This species is characterised by its scabrate central body and long, solid, cylindrical processes. Under the scheme of Staplin *et al*. (1965) this form would probably be considered a species of *Solisphaeridium* Staplin *et al*. (op. cit.).

Affinities

Possibly gymnodinialean ?

Micrhystridium sp. B

Plate IX., Figure 7.

Description

Cyst subspheroidal to angular, possibly being constructed of two wall layers. Test is scabrate to microgranulate. Processes are few in number, long, hollow, connect to the interior of the cyst, latispinous, erect to curved, tapering and distally acuminate. The pylome was not observed.

Figured Material

JW66-13-13(2) at 109.0-39.4; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 15.0(22.3)31.0 microns, length of short axis 11.0(19.3) 29.0 microns, processes range in length from 3-14 microns. Twenty-seven specimens

were measured, the number of specimens studied.

Remarks

This species is characterised by its hollow, distally acuminate processes and scabrate to microgranulate central body. Thie form would also be a species of Micrhystridium under the scheme of Staplin et al. (1965).

Affinities

Possibly gymnodinialean ?

Micrhystridium sp. C

Plate IX., Figure 4.

Description

Cyst subspheroidal to ovoidal, appears to be made up of a single wall layer. Test microgranulate. Processes are long, hollow, connect to the interior of the cyst, latispinous, erect, tapering and distally multifurcate into a number of solid branches which may themselves be distally bifid. A pylome was not observed.

Figured Material

JW66-13-10(3) at 93.5-38.1; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 17.0(23.1)25.0 microns, length of short axis 12.0(17.7) 20.0 microns, processes range in length from 7-20 microns. Seven specimens were measured, the number of specimens studied.

Remarks

This species is characterised by the multifurcate tips of its processes. Under Staplin et al. (1965) these forms would be placed in the genus Multiplicisphaeridium Staplin restrict Staplin 1965.

Affinities

Possibly gymnodinialean ?

Micrhystridium sp. D

Plate IX., Figure 6.

Description

Cyst subspheroidal, made up of two wall layers, the outer constructing the process. Test scabrate. Processes few to many, hollow, long, slender, erect to curved, and distally flared with an entire or bifid tip. A large irregular pylome was seen in one specimen.

Figured Material

JW66-13-10(2) at 94.6-43.2; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 14.0(23.8)35.0 microns, length of short axis 11.0(16.7) 23.0 microns, processes range in length from 6-14 microns. Nine specimens were measured, the number of specimens studied.

Remarks

This species is characterised by its scabrate central body and the possession of hollow processes that are distally flared.

Affinities

Possibly gymnodinialean ?

Subgroup Herkomorphitae Downie *et al*. 1963

Genus *Cymatiosphaera* Wetzel emend. Deflandre 1954

Type Species: *Cymatiosphaera radiata* Wetzel 1933; O.D.

Remarks

These acritarchs possess tests that are divided into polygonal fields that

cannot be rationalised into a tabulation. Processes may be present arising from the angles of these fields.

Cymatiosphaera sp. A

Plate IX., Figure 8.

Description

Cyst subspheroidal to polygonal, appears made up of two wall layers. Test microgranulate and divided into a number of fields by thickened raised sutures. No pattern can be deciphered for these fields. Processes are gonal, solid, slender, erect to curved, cylindrical and distally bifurcate or trifurcate the tips of each branch may be bifid or acuminate. No pylome was observed.

Figured Material

RH69-13-1(1) at 106.0-47.1; Bearpaw Formation, southern Alberta.

Dimensions

Length of long axis 18.0(21.2)31.0 microns, length of short axis 13.0(17.6) 22.0 microns, processes range in length from 3-19 microns. Ten specimens were measured, the number of specimens studied.

Remarks

This species is characterised by the nature of the processes and the thickened raised sutures. It has been remarked that this form is similar to the genus Spiniferites, however, in no way can the fields visible on these forms be rationalised into a tabulation. This form is a distinct morphotype.

Affinities

Possibly gymnodinialean ?

CHAPTER VII

INTERPRETATION OF THE BEARPAW PHYTOPLANKTONIC RECORD

Introduction

The phytoplanktonic record of the Bearpaw Formation may be interpreted in a number of different ways. Data collected during the course of this investigation was amassed with a view to increasing our knowledge of Campanian dinoflagellates and acritarchs. The range charts compiled by Sarjeant (1967) quite clearly show the lack of information, due to the paucity of data, for this time interval.

Is the Bearpaw Formation characterised by a particular assemblage of dinoflagellate cysts and acritarchs ? How does this assemblage fit into the overall picture of these organisms in the Upper Cretaceous ? These are general questions but are important in evaluating the usefulness of these fossils for stratigraphic purposes. It is generally accepted that they are of value and certainly Davey (1969) has demonstrated a long range correlation for the Cenomanian using dinoflagellate cysts. There is still, however, a lack of formally designated zonal schemes based on dinoflagellates and acritarchs. The only scheme known to the author is that of Clarke & Verdier (1967) for the Chalk of the Isle of Wight, England. There is no reason why a zonal scheme for the entire Cretaceous should not be erected in the future, to complement the zonal schemes, based on other taxa, already in use.

To be a little more specific - is it possible to divide the local sections of the Bearpaw Formation of southern Alberta into biostratigraphic units ? Can these units be traced from one locality to another ?

An often ignored problem is the interpretation of the palaeoenvironment of the Bearpaw sea. Does the dinoflagellate and acritarch record give us any pertinent information to this end ? In the present study of the Bearpaw Formation the author is fortunate to have foraminiferal control on one of the sections studied so that a

palaeoenvironmental approach is by no means impossible.

It is intended, however, to look at each of these questions in turn.

The Bearpaw Assemblage

The Bearpaw Formation contains a distinct assemblage of dinoflagellate cysts and acritarchs. In particular it is characterised by the presence of the genera *Deflandrea*, *Diconodinium* and *Lejeunia*.

To characterise the assemblage further it is necessary, though difficult, to give some idea of the relative proportions of certain of the cysts present. It should be realised that certain cysts appear in greater numbers in strew mounts than others. In a purely qualitative sense, therefore, the following three categories are used:- "common", "occasionally common" and "rare".

A system such as that used by Davey (1969) is regarded as being not very realistic. The final proportion of cysts as seen in the strew mounts is subject to a number of factors. The first, of course, is the primary production of the cysts by the dinoflagellates and acritarch-producing organisms in the surface waters of the sea. This in itself is not as yet fully understood and may or may not reflect the proportions of the existing thecal stages. Once a cyst has been produced, it will act as a sedimentary particle and will be subject to all the factors inherent in sedimentary processes in the marine environment as Muller (1959), Traverse & Ginsberg (1966), Cross *et al*. (1966) and others have demonstrated. The cysts may then be affected by preservational effects and then finally by all the biases commonly associated with collecting and preparing palynological samples.

Nevertheless the Bearpaw assemblages studied always had high proportions of the following cysts : *Deflandrea spectabilis*, *Diconodinium firmum* and *Oligosphaeridium pulcherrimum*. These species are regarded as being "common". Some of the samples, in addition to those mentioned above, contain high proportions of *Canningia senonica*, *Microdinium irregulare*, ?*Lejeunia ampla*, *L*. *tricuspis*,

Odontochitina operculata, Cyclonephelium distinctum, Hystrichosphaeridium tubiferum var. brevispinum and Deflandrea korojonensis. These latter species are regarded as "occasionally common". All other species recovered from the Bearpaw Formation are "rare".

A perusal of the known stratigraphic ranges of dinoflagellate species, after Sarjeant (1967), reveals that only two species are restricted to the Campanian; these are Deflandrea macrocysta and D. microcantha Cookson & Eisenack. In fact only nine species are known to be restricted to the Santonian-Maestrichtian interval in the world. Of all these restricted species only three were recovered from the Bearpaw Formation viz. Deflandrea macrocysta, D. korojonensis and D. spectabilis. In addition five new species have been recorded in the present study but it remains to be seen if these are restricted to the Campanian.

Comparisons with other assemblages are difficult to make as very little work has been done with Campanian microplankton. Cookson & Eisenack (1960) described some types from western Australia. It is of interest to note the similarities of their Deflandrea species with those from the Bearpaw Formation. In addition, however, they recorded a unique collection of species.

Clarke & Verdier (1967) recorded very few species of dinoflagellate cysts and acritarchs from the Campanian of the Isle of Wight. Species common to their and the present assemblage are Exochosphaeridium bifidum, Cyclonephelium distinctum and Odontochitina operculata.

Vozzhennikova (1967), in her tables of diagnostic species lists the following for the Campanian of Kazakhstan:- Gymnodinium kasachstanium Vozzhennikova, Australiella cooksoni (Alberti) Vozzhennikova, A. granulifera (Manum) Vozzhennikova, Albertia curvicornis Vozzhennikova and Cooksoniella manumi Vozzhennikova. Similarities exist with the Bearpaw assemblages especially with regard to the Deflandrea species. The genera Australiella and Cooksoniella are

new genera of Deflandrea - like cysts.

Oltz (1969) recorded the presence of Deflandrea aff. microgranulata Stanley, Deflandrea sp., Hystrichosphaeridium aff. tubiferum (Ehr.) Deflandre, Hystrichosphaeridium., cf. Gonyaulacysta, Forma 'A', Forma 'B', Forma 'C', and Paleotetradinium sp. from the Bearpaw Formation of east central Montana. His assemblage appears similar to that described in this work but a full comparison is not possible as he failed to place his specimens in formalised taxa. A list of the fossil pollen and spores recovered from the Bearpaw Formation by Oltz (op. cit.) and Norton & Hall (1969) is given in Appendix B.

Recently Davey (1969b, 1969c) described dinoflagellate cysts from the Campanian of South Africa. His assemblages do not appear comparable except for the presence of Diconodinium spp. and Exochosphaeridium bifidum.

In general it appears that there is a world-wide similarity in the Deflandrea species, bearing in mind the taxonomic difficulties associated with this genus, but differences as far as the rest of the assemblages are concerned. No other assemblage, therefore, is directly comparable to that under study.

Local Biostratigraphy

The Bearpaw Formation contains a number of informal assemblage zones. Each of these assemblage zones may be further divided into a number of subzones. Since the most complete section studied was that at Lethbridge this will be dealt with first before a comparison is made with the Cypress Hills section.

At Lethbridge three informal assemblage zones may be recognised. These have been labelled I to III on Figure 17.

The first assemblage zone encompasses a body of rock contained between 10 feet above the base of the Bearpaw to approximately 160 feet above the base of the formation. This assemblage zone contains the following dinoflagellate cysts and acritarchs:-

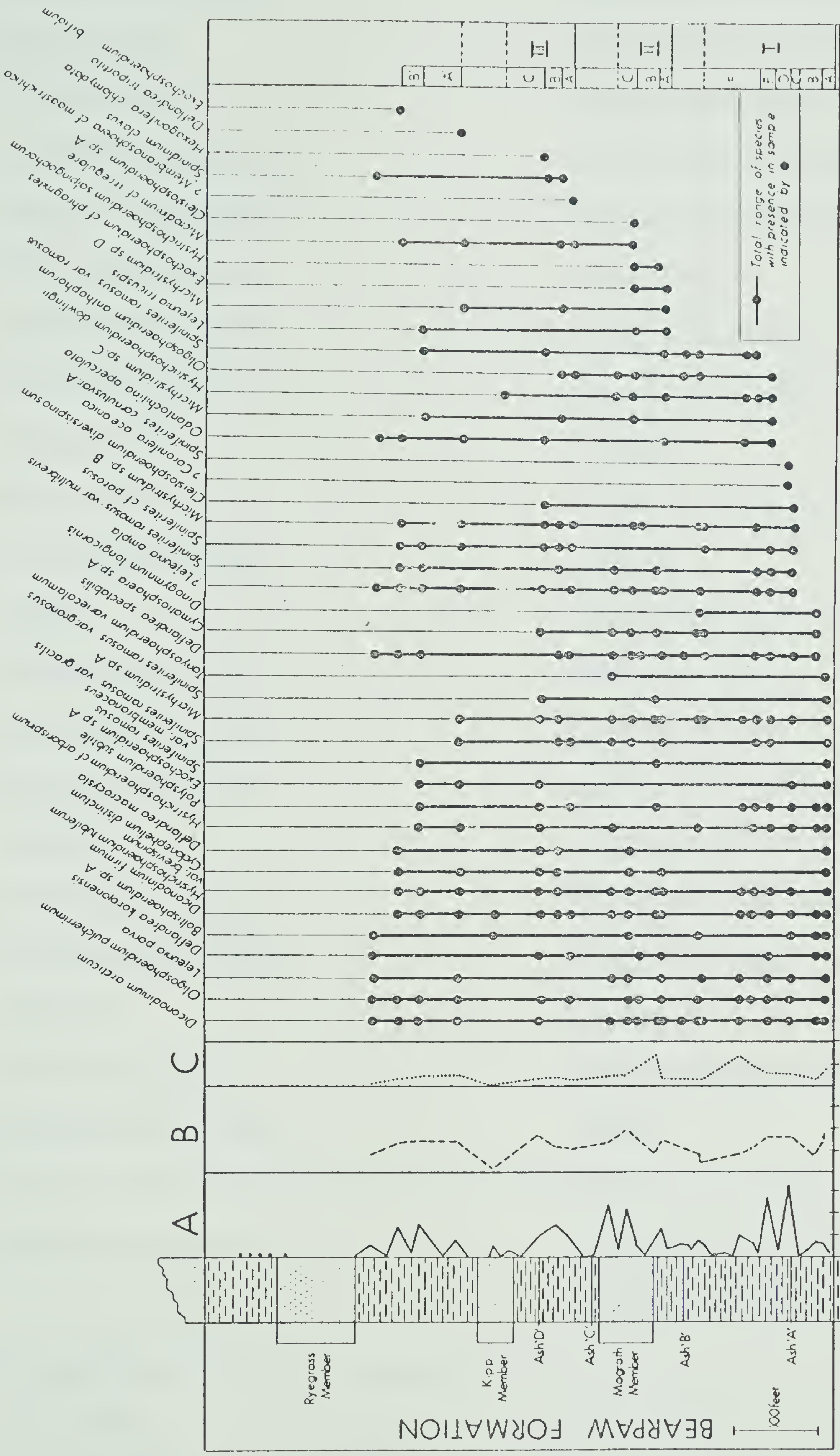

Figure 17: Vertical ranges of the dinoflagellate cysts and acritarchs recovered from the Lethbridge sections of the Bearpaw Formation together with the proposed biostratigraphic zonation.

Column A - Percentages of phytoplankton per sample.
Column B - Number of dinoflagellate cyst species per sample.
Column C - Gonyaulacacean ratio.

Diconodinium arcticum
Lejeunia parva
Baltisphaeridium sp. A
Hystrichosphaeridium tubiferum var. brevispinum
Deflandrea macrocysta
Polysphaeridium subtile
Spiniferities ramosus var. membranaceus
Micrhystridium sp. A
Tanyosphaeridium variecalamum
Deflandrea spectabilis
Dinogymnium longicornis
Spiniferites ramosus var. multibrevis
Spiniferites cf. porosus
Cleistosphaeridium diversispinosum
?Coronifera oceanica
Odontochitina operculata
Oligosphaeridium pulcherrimum
Deflandrea korojonensis
Diconodinium firmum
Cyclonephelium distinctum
Hystrichosphaeridium cf. arborispinum
Exochosphaeridium sp. A
Spiniferites ramosus var. gracilis
Spiniferites ramosus var. granosus
Cymatiosphaera sp. A
?Lejeunia ampla
Micrhystridium sp. B
Spiniferites cornutus var. A
Micrhystridium sp. C
Oligosphaeridium anthophorum
Spiniferites ramosus var. ramosus
Hystrichosphaeridium dowlingii

of these, six species are restricted to this assemblage zone. These are as follows:-

Spiniferites cornutus var. A
Dinogymnium longicornis
?Coronifera oceanica

The assemblage zone has also been subdivided into a number of subzones designated A to F in Figure 17; these are based on first appearances and are somewhat artificial being dependant on the sample distribution, etc.

The second informal assemblage zone is contained in a body of rock 190 feet above the base of the formation to approximately 260 feet above the base of the formation. This assemblage zone contains the following dinoflagellate cysts and acritarchs:-

Diconodinium arcticum

Lejeunia parva

Baltisphaeridium sp. A

Hystrichosphaeridium tubiferum var. *brevispinum*

Deflandrea macrocysta

Polysphaeridium subtile

Spiniferites ramosus var. *membranaceus*

Micrhystridium sp. A

Tanyosphaeridium variecalamum

Cymatiosphaera sp. A

Spiniferites ramosus var. *multibrevis*

Micrhystridium sp. B

Micrhyristridium sp. C

Oligosphaeridium anthophorum

Lejeunia tricuspis

Hystrichosphaeridium salpingophorum

Exochosphaeridium cf. *phragmites*

Microdinium irregulare

Oligosphaeridium pulcherrimum

Deflandrea korojonensis

Diconodinium firmum

Cyclonephelium distinctum

Hystrichosphaeridium cf. *arborispinum*

Exochosphaeridium sp. A

Spiniferites ramosus var. *gracilis*

Spiniferites ramosus var. *granosus*

Deflandrea spectabilis

?*Lejeunia ampla*

Spiniferites cf. *porosus*

Cleistosphaeridium diversispinosum

Odontochitina operculata

Hystrichosphaeridium dowlingii

Spiniferites ramosus var. *ramosus*

Micrhystridium sp. D

of these, five species appear restricted to this assemblage zone. These are as follows:-

Hystrichosphaeridium salpingophorum
Exochosphaeridium cf. *phragmites*
Cleistosphaeridium sp. A

This zone has also been subdivided into subzones A-C based on first appearances, as may be seen in Figure 17.

The third assemblage zone is contained in a body of rock from 305 feet above the base of the Bearpaw to approximately 540 feet above the base of the formation. This assemblage zone contains the following dinoflagellate cysts and acritarchs:-

Diconodinium arcticum
Lejeunia parva
Baltisphaeridium sp. A
Hystrichosphaeridium tubiferum var. *brevispinum*
Deflandrea macrocysta
Polysphaeridium subtile
Spiniferites ramosus var. *membranaceus*
Micrhystridium sp. A
Deflandrea spectabilis
?*Lejeunia ampla*
Spiniferites cf. *porosus*
Cleistosphaeridium diversispinosum
Odontochitina operculata
Hystrichosphaeridium dowlingii
Oligosphaeridium pulcherrimum
Deflandrea korojonensis
Diconodinium firmum
Cyclonepheluim distinctum
Hystrichosphaeridium cf. *arborispinum*
Exochosphaeridium sp. A
Spiniferites ramosus var. *gracilis*
Spiniferites ramosus var. *granosus*
Cymatiosphaera sp. A
Spiniferites ramosus var. *multibrevis*
Micrhystridium sp. B
Micrhystridium sp. C
Oligosphaeridium anthophorum
Lejeunia tricuspis

Spiniferites ramosus var. *ramosus*

Micrhystridium sp. D

?*Membranosphaera* cf. *maastrichtica*

Microdinium irregulare

Spinidinium clavus

Deflandrea tripartita

Hexagonifera chlamydata

Exochosphaeridium bifidum

of these, seven species appear restricted to this assemblage zone. These are the following:-

? *Membranosphaera* cf. *maastrichtica*

Hexagonifera chlamydata

Spinidinium clavus

Deflandrea tripartita

Exochosphaeridium bifidium

This assemblage zone has been subdivided into three subzones A-C. In addition, two further subzones have been recognised, and these are labelled A' and B' in Figure 17, but it is unsure whether they are part of this assemblage zone or not.

In the Cypress Hills sections only two of these zones are recognised as part of the Manyberries Member could not be sampled because of poor exposure and lack of stratigraphic control. The lower assemblage zone can be recognised, see Figure 18, but it is here seen to contain eleven species that appear restricted. In addition to those already mentioned for this zone the following are also restricted:-

Canningia cf. *rotundata*

Komewuia cf. *glabra*

Deflandrea granulifera

Cleistosphaeridium sp. A

Cribroperidinium sp. A

Dinogymnium cf. *albertii*

Tanyosphaeridium variecalamum

Micrhystridium sp. A

The upper assemblage zone is also present in the Cypress Hills although its full limits cannot be ascertained, through lack of samples. In addition to the species already listed as being restricted to this assemblage zone the following are also

restricted:-

Deflandrea echinoidea

Cymatiosphaera sp. A

Apteodinium sp. A

Micrhystridium sp. C

?Uvatodinium cf. nasutum

The author is hesitant in his recognition of this assemblage zone in that only one of the restricted species is common to both areas.

The subzones of the lower assemblage zone do not exactly correlate in the two areas but they both signify a particular sequence of events. These subzones are restricted, therefore, and their usefulness even in local correlation is questioned.

The recognition of all these informal assemblage zones rests, in large part, on species that form only a very small proportion of the total assemblage. In attempting to trace the Lethbridge zones to the Cypress Hills two key species have been used i.e. ?Coronifera oceanica and ?Membranosphaera cf. maastrichtica. It is doubtful that they are as reliable as this usage would indicate. A good clear correlation between these two areas is not then possible but both areas do reflect, in the distribution of the dinoflagellate cysts and acritarchs the initial transgression of the Bearpaw sea.

Palaeoenvironment of the Bearpaw

The Lethbridge section of the Bearpaw Formation was examined for its foraminiferal content by Anan-Yorke (1969). He recognised six cycles of water depth fluctuations and it is suggested that salinity changes accompanies these fluctuations. An attempt has been made to recognise these fluctuations using the dinoflagellate cysts and acritarchs.

A record was kept of the percentage of dinoflagellate cysts and acritarchs present in each sample examined. This information is shown in column A of Figures 17 and 18. In addition, in those samples that were studied in detail, i.e. those where the percentage of dinoflagellates and acritarchs rose to 10% or more a record

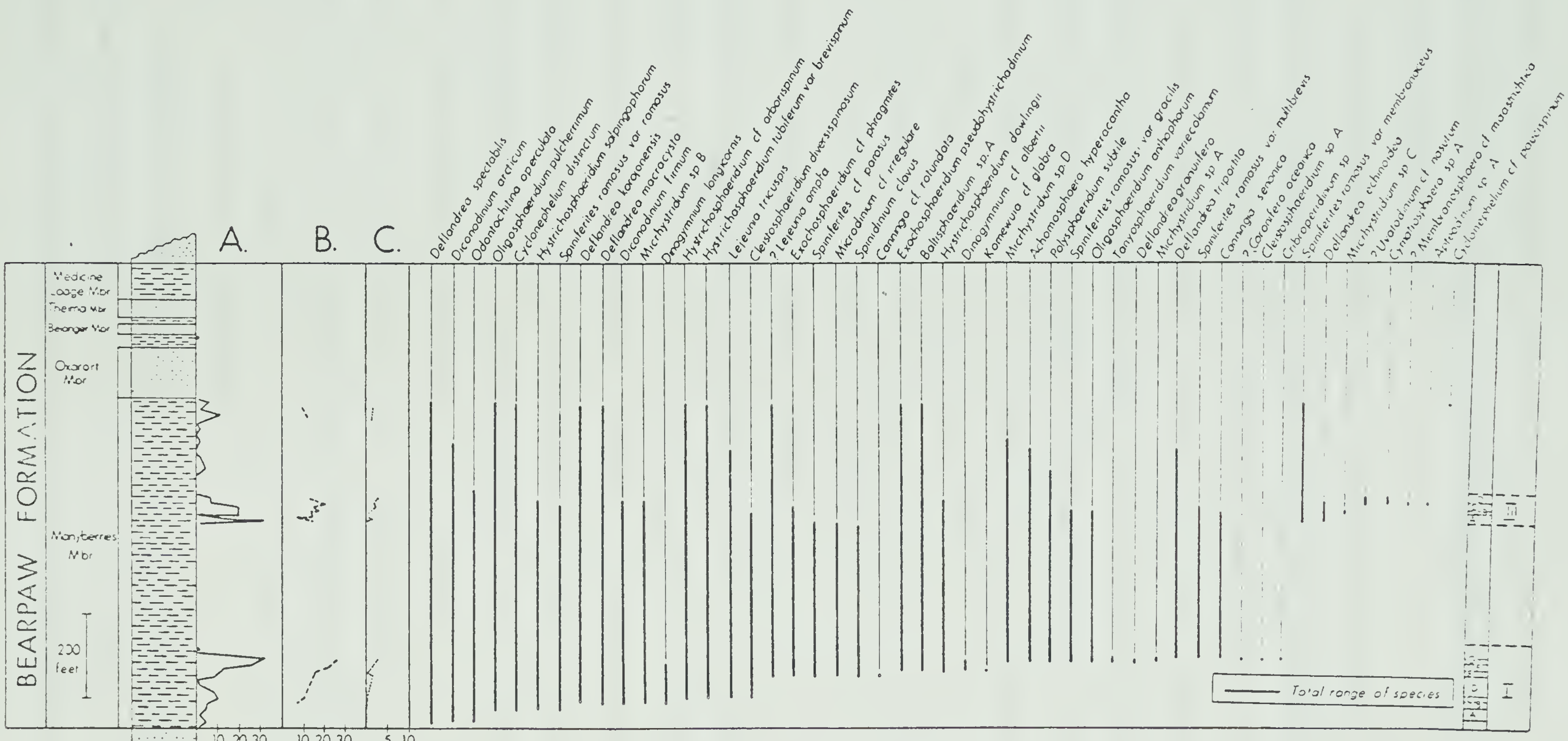

Figure 18: Vertical ranges of the dinoflagellate cysts and acritarchs recovered from the Cypress Hills sections of the Bearpaw Formation together with the possible equivalent biostratigraphic units to those proposed for the Lethbridge area. Column explanations the same as those given for Figure 17.

of the number of dinoflagellate species was kept, and this is shown in column B of the two range charts. Column C records the gonyaulacacean ratio for each of the samples studied in detail.

The gonyaulacacean ratio is simply the number of cysts that have a gonyaulacacean affinity divided by the number of cysts having a peridiniacean affinity. If we assume that conditions have not radically altered from today, then it is fairly clear that in an open marine environment the number of gonyaulacacean dinoflagellates species is relatively higher than the number of peridiniacean dinoflagellate species (Schiller 1937). We must assume that this is reflected in the cyst populations. In Wall (1967) the calculated gonyaulacacean ratio is 18.0 for cysts collected from deep sea cores in the Caribbean, and Wall & Dale (1968a) has a calculated gonyaulacacean ratio of 0.44 for a near shore cyst population at Woods Hole, Massachusetts. Freshwater assemblages have high proportions of peridiniacean dinoflagellates and low proportions of gonyaulacacean dinoflagellates as may be seen in Eddy (1930) and Thompson (1947, 1950). This picture is, however, slightly complicated by the appearance of certain other dinoflagellate families such as the Glenodiniopsidaceae, Glenodiniaceae and the Heterodiniaceae. Unfortunately very little is known of freshwater dinoflagellate cysts and much less about their affinities, however, Norris & McAndrew (in press) recorded the presence of cysts of obvious peridiniacean affinities from a freshwater lake in Minnesota. It was decided to test this rather empirical idea using the Bearpaw assemblages. The gonyaulacacean ratio was calculated for each of the samples studied in detail using cysts for which their natural affinities are known or reasonably assured. The results are shown in column C of the range charts.

An inspection of these three columns (A-C) from the Lethbridge section reveals some interesting features. In general it may be seen that an increase in the percentages of the dinoflagellates and acritarchs is accompanied by an increase in

the number of species and by an increase in the gonyaulacacean ratio. It is concluded that this relationship is reasonably good evidence to pin-point the appearance of open marine conditions. The author has no justification in setting definite limits on this environment, in terms of salinity, temperature etc, so the term open marine is used only in a relative sense. These open marine conditions may be indicative of periods of maximum extent of the Bearpaw sea such that the shoreline is distant with the accompanying normal salinity for ocean waters. It might, however, indicate periods when the nutrient content of the sea was optimum for the phytoplankton. The first interpretation seems the more reasonable but there is at present insufficient evidence to be dogmatic about any of the postulated causes.

Using this information it is interpreted that an initial flooding or transgression is represented by the lowermost 150 feet of the formation with optimum open marine conditions between 60-100 feet above the base of the formation. A second period of open marine conditions is represented from approximately 180-240 feet above the base of the formation and a period of fluctuating conditions represented from approximately 310-550 feet above the base of the formation. It is suggested that open marine or optimum conditions are represented at approximately 340 and 460 feet above the base of the formation. Many more minor fluctuations are apparent in column A, but on an individual basis these are difficult to explain and may indeed be entirely spurious.

In comparing the results from the dinoflagellate cysts and acritarchs with those from the foraminiferids a close similarity is evident. Anan-Yorke (1969) categorizes his zones as follows:-

1) Basal 56 feet - lagoonal, brackish.
2) 56-115 feet - open marine.
3) 115-200 feet - lagoonal, brackish.
4) 200-450 feet - deeper water nut not as deep as in 2.
5) 450 feet of Ryegrass Member - lagoonal.

Anan-Yorke's zone 2) corresponds quite well with the time of optimum conditions for the initial flooding of the Bearpaw sea as documented by the dinoflagellates and acritarchs. These fossils also pick out a second period of optimum conditions at the level of the Magrath Member which Anan-Yorke unfortunately failed to examine for foraminiferids because of a lack of samples. Dinoflagellate and acritarch evidence suggests the same fluctuating conditions for zone 5) of Anan-Yorke, although the microplankton evidence seems to be a little more accurate in defining times of optimum conditions especially with regard to zone 5).

In the Cypress Hills the period of initial flooding can be recognised together with one of the open marine periods in the final stage of the fluctuating conditions.

Certain dinoflagellate cysts and acritarchs seem to indicate particular environments with regard to the Lethbridge area. Shallow, near shore environments appear to be indicated by :-

<u>Deflandrea korojonensis</u>
<u>Tanyosphaeridium variecalamum</u>
<u>Dinogymnium longicornis</u> *
<u>Cleistosphaeridium diversispinosum</u>
?<u>Coronifera oceanica</u>
<u>Micrhystridium</u> sp. C
<u>Baltisphaeridium</u> sp. A
<u>Spiniferites cornutus</u> var. A
<u>Oligosphaeridium anthophorum</u>
<u>Micrhystridium</u> sp. D *
<u>Exochosphaeridium</u> cf. <u>phragmites</u>
<u>Lejeunia tricuspis</u> *
?<u>Membranosphaera</u> cf. <u>maastrichtica</u> *

The species marked by an asterisk also seem restricted to the same environment in the Cypress Hills areas. The following species appear to be tolerant to near-shore to open marine conditions:-

<u>Diconodinium arcticum</u> *
<u>Diconodinium firmum</u> *
<u>Micryhstridium</u> sp. A
<u>Oligosphaeridium pulcherrimum</u>*
<u>Polysphaeridium subtile</u>
? <u>Lejeunia ampla</u> *

Spiniferites ramosus var. *multibrevis*

Odontochitina operculata *

Hystrichosphaeridium dowlingii

The species marked by an asterisk occupied a similar position in the Cypress Hills sections. No species were restricted to the open marine environment . This assessment is by visual inspection of the presence or absence of cyst species in relationship to the graphs portrayed in volumns A-C of Figures 17 and 18.

It is also interesting to note that the Cypress Hills sections contain a higher number of microplankton species, possibly indicative of generally deeper water conditions. A comparison of the initial transgression of the Bearpaw sea in the Lethbridge and Cypress Hills reveals a close similarity in the build up of the numbers of dinoflagellates and acritarchs, in species and in the gonyaulacacean ratio. A species by species match, however, cannot be made.

Summary

The upper Campanian dinoflagellate and acritarch population of the Bearpaw sea are used to subdivide the Bearpaw Formation of southern Alberta into three informal assemblage zones that are intimately connected with the environmental conditions at that time. In effect three intervals can be recognised where open marine/optimum conditions existed.

Unfortunately much of the work of stratigraphic palynologists pays little attention to palaeoenvironments. Such semi-quantitative procedures as those described earlier would allow the recognition of palaeoenvironmental changes, with regard to the dinoflagellate and acritarch populations. This would prevent over emphasis of chronostratigraphic problems and would allow a fuller understanding of all the problems involved.

Certain limitations do exist. The palynologist, in studying microplankton, is looking at the cyst and not the motile stage of the life cycle. To what extent does the cyst population reflect the true population of these organisms in their

natural habitat ? Under what conditions do cysts form and what factors have affected their distributions in the sediments from which they are extracted ? These two, as yet largely unanswered, questions clearly point out the present gross limitations of all dinoflagellate and acritarch research.

CHAPTER VIII

CONCLUSIONS

The Bearpaw Formation contains an assemblage of fossil dinoflagellate cysts and acritarchs. Certain of these forms appear to characterise the formation, especially the high proportions of the genera Deflandrea, Lejeunia, and Diconodinium, and to a lesser extent the genera Hystrichosphaeridium, Oligosphaeridium and Spiniferites. In numbers of species it appears that the trend toward the poor assemblages of the Maestrichtian and Danian is foreshadowed here; certainly the Bearpaw assemblages are not as rich as those of the Cenomanian and Eocene, (see Davey 1969 and De Coninck 1968).

In this, the first, taxonomic study of Campanian dinoflagellates and acritarchs sixty-two species of dinoflagellates, belonging to sixteen cyst-families, and six species of acritarchs have been described. Six of the dinoflagellate species are described as new, but many more, informally treated in this work, are thought to be new. The ranges of several species have been extended. The classification of Sarjeant & Downie (1966) is used for the dinoflagellates and that of Downie et al. (1963) for the acritarchs. The affinities of the fossil phytoplankton with modern families is given where known or reasonably assured to facilitate the use of these fossils as palaeoenvironmental indicators. This is a new approach to this type of problem.

During the systematic study of the dinoflagellates and acritarchs several problems became apparent. The first is a need for a critical look at the genus Deflandrea especially in the light of the new general and emendations proposed by Vozzhennikova (1967). The genus Lejeunia has been emended in an attempt to make the taxon more discrete. Further study of the genus Lejeunia is necessary as it appears that cysts with same overall morphology have transapical archeopyles,

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as recorded by Norris (pers. comm.) and some have apical archeopyles (this thesis). Perhaps this is a case for convergent evolution or homeomorphy in dinoflagellate cysts (?)

It would appear, from published range charts, that the Campanian Stage is characterised by the presence of such dinoflagellate species as Deflandrea macrocysta and D. microcantha and to a lesser extent by D. korojonensis and D. spectabilis, with other similar species of Deflandrea. The Bearpaw Formation contains D. macrocysta, D. korojonensis and D. spectabilis. The Campanian age of the Bearpaw Formation of southern Alberta is confirmed with the presence of the above mentioned cysts. Unfortunately there are, as yet, not enough dinoflagellate data available to confirm the Upper Campanian age of the formation.

It is, however, possible to divide the Bearpaw Formation at Lethbridge into three informal assemblage zones, that have been labelled I to III. These assemblage zones are intimately connected with the palaeoenvironment of the Bearpaw sea. The basal assemblage zone and a part of the uppermost assemblage zone can be recognised, with some reserve, in the Cypress Hills area.

In addition to the "classic" approach of dividing a formation into biostratigraphic units certain interesting palaeoenvironmental observations can be made.

If the presence or absence of a particular species in a sample, the percentages of dinoflagellates and acritarchs, the number of dinoflagellate species per sample, and the gonyaulacacean ratio are plotted on the range charts, a certain amount of palaeoenvironmental control is immediately placed on the biostratigraphy. The gonyaulacacean ratio, empirically based, is used here as a measure of different environments, being plausibly a function of different salinities. A comparison was made with the foraminiferid zonation of the Lethbridge sections, and a fairly close agreement was apparent. It is suggested that the gonyaulacacean

ratio has a potential for this purpose and it is hoped that with further studies of modern material that this potential will be utilised.

It is at present very difficult to qualify the terms near-shore, off-shore, open marine and optimum as used in this work. They may, however, be used in a relative sense. Certain species have been tentatively picked out as indicating a particular environment, but this is as yet a hazardous procedure. The hypothesis that the genus *Deflandrea* is a near-shore indicator (Burgess 1969) is not particularly borne out by this study, although near-shore in the sense of Burgess (op. cit.) may be "near-shore to open marine" in the terms of this study. Similarly Downie *et al.* (1969a) suggested that acanthomorphitid acritarchs are near-shore indicators. Davey (1969a) suggested that the genus *Cyclonephelium* had a preference for an open marine environment, this suggestion is here verified to a certain extent, but it certainly cannot be used as an unequivocal open marine (open water) indicator.

Finally we can ask what we know of the palaeoenvironment of the Bearpaw sea. Tourtelot (1962) regarded the Pierre Formation and equivalent rocks as being deposited in a narrow shallow sea that extended both northwards and southwards across the western interior of the United States. It was suggested that to the north the sea was connected to world oceanic waters and to the south, from time to time, with seas in the Gulf Coast region.

Caldwell (1968) suggested that at all times the Bearpaw sea was shallow and represented littoral-neritic conditions. It was also suggested that although the waters that covered the sea bed were agitated by wave and current action, they were seldom of sufficient strength to damage the shells of sessile bivalves that lived on the sea floor. Although clays generally represent deep water deposition, the clays contained in the Bearpaw Formation all have high proportions of silt suggestive of shallow water conditions. Even those clays that are thought to represent the deeper water conditions e.g. clays of the Snakebite Member, have silt contents of 35-45%. The benthonic molluscan fauna is also suggestive of shallow

water conditions. Caldwell (op. cit.) finally considered that the evidence suggested a depth range of between zero and 150 feet.

Tourtelot & Rye (1969) gave 25°C as the palaeotemperature of the Campanian seaway in Canada based on oxygen isotope work on belemnites and baculitids. The genus Inoceramus Sowerby and the occasional specimens of the baculitids had light oxygen isotope compositions that gave anomalously high palaeotemperature figures. These anomalous results are explained as partly the result of metabolic fractionation of oxygen and partly the result of the dilution of sea water by fresh-water. This latter condition apparently did not affect the marine benthos and nekton but may well have had some effect on the phytoplankton.

Mello (1969), in a study of the foraminiferids from the upper part of the Pierre shale in north-central south Dakota, picked out, from his foraminiferid data, a period of deep water conditions within a period of fairly shallow water conditions. Nevertheless he estimated that the depth of the sea in south Dakota never exceeded 200 feet.

The present results suggest the presence of fluctuating conditions in the Bearpaw sea. Two periods of open marine conditions have been recognised with at least two sub-periods of marine conditions existing in the uppermost "assemblage zone". It should be re-emphasised that the factors controlling these differences are not fully known. It may be a depth, salinity, nutritional, temperature or a combinational control. Wall & Dale (1968a) have suggested that the present day distribution of dinoflagellates is climatically controlled by water temperatures and they give the following data for Spiniferites ramosus in Wall & Dale (1970). This cyst, recovered from the Bearpaw Formation, was recorded by Wall & Dale (op. cit.) from Harrington Sound, Bermuda from water with a temperature range of 16.5-28.5°C. Experiments showed that these cysts were hibernating spores in an environment that had a definite seasonality. This cyst has, however, also been recovered from temperate latitudes.

The Bearpaw dinoflagellate assemblages may or may not show fluctuations due to temperature controls. The apparent effectiveness of such a parameter as the gonyaulacacean ratio suggests more of a salinity control. A whole new area of research is opening up with respect to the palaeoecology of the dinoflagellates and acritarchs and it is hoped that it will continue in the future.

CHAPTER IX

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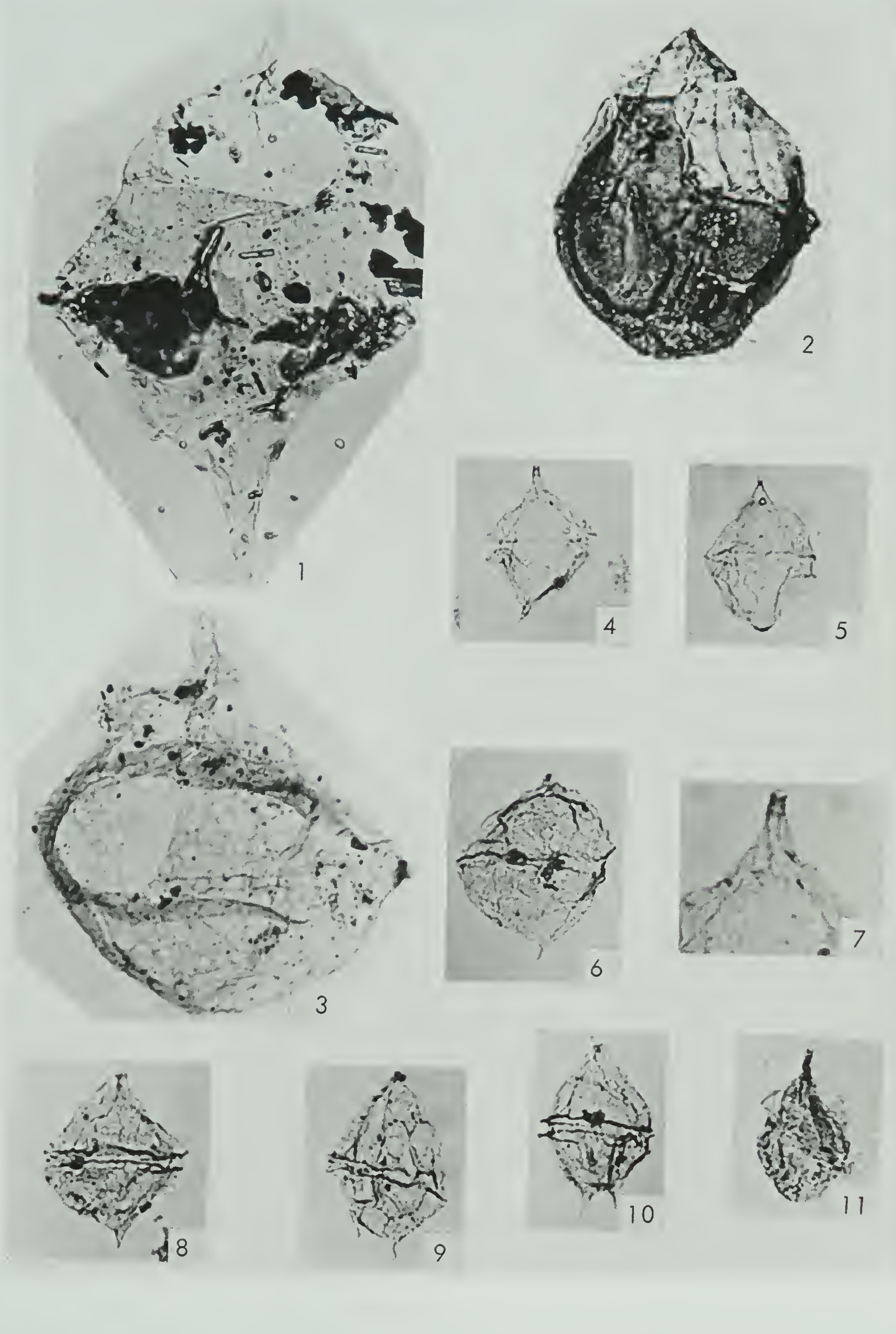
PLATE I

All figures are at a magnification of x600 unless otherwise stated.

PLATE I



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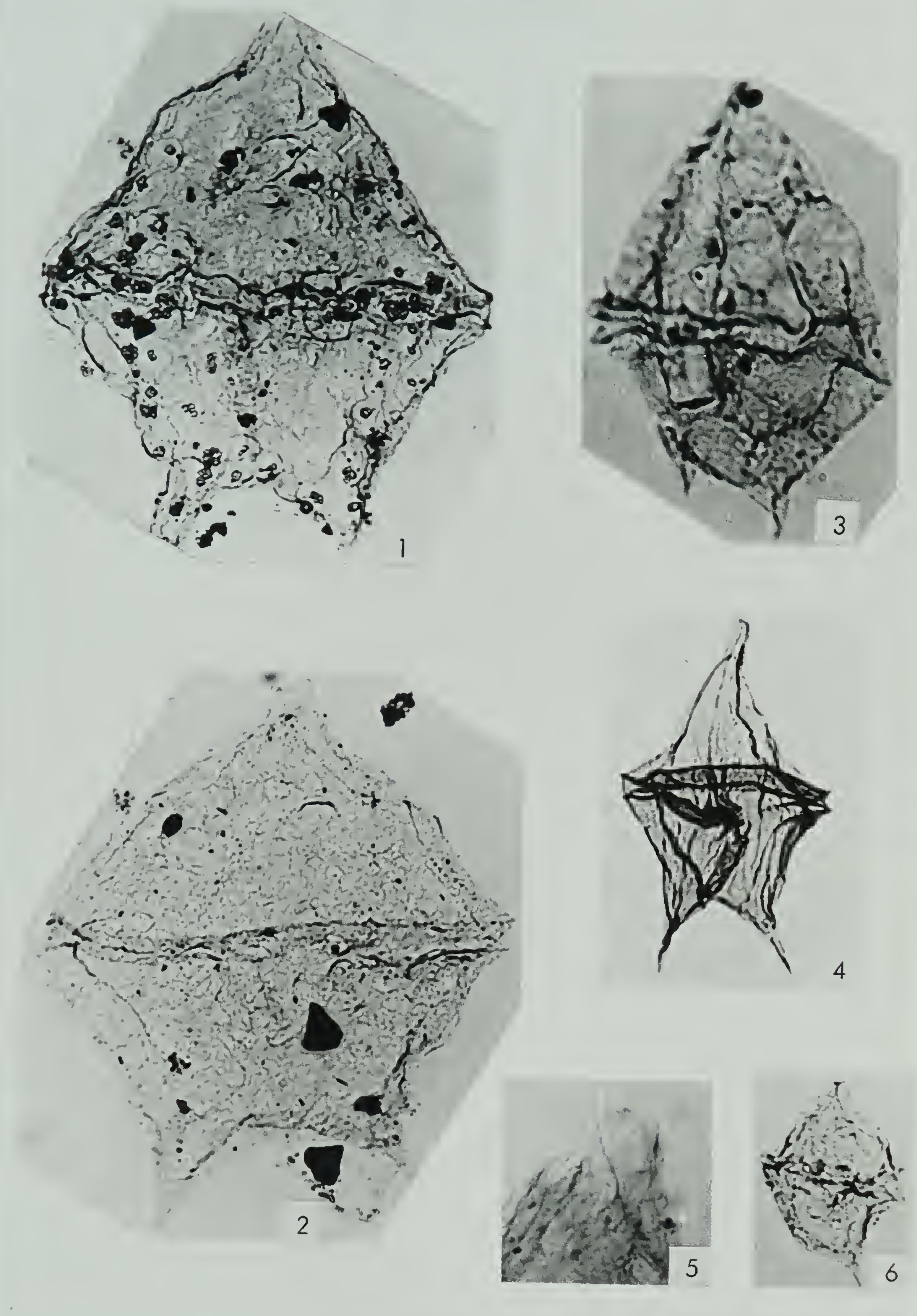

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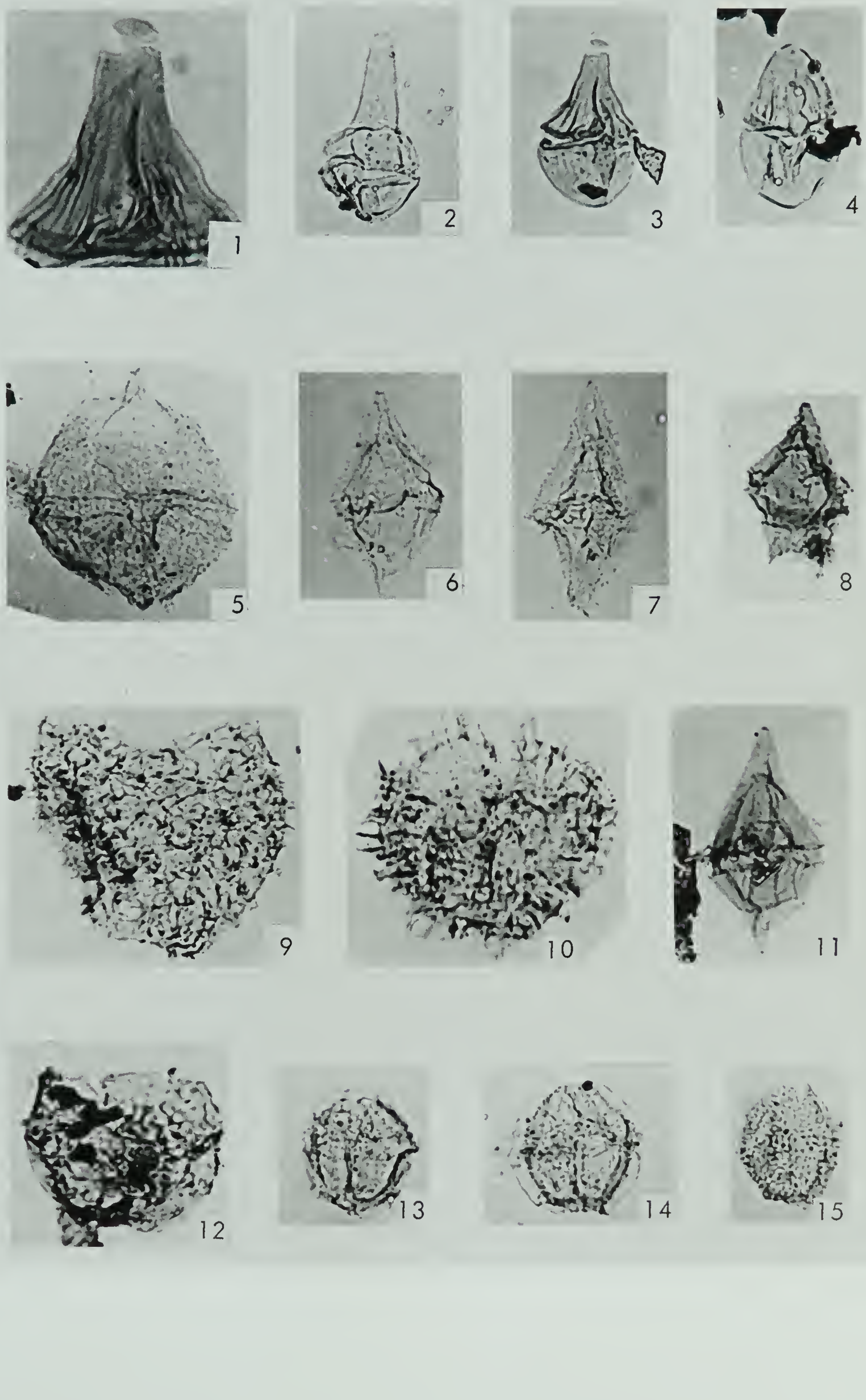

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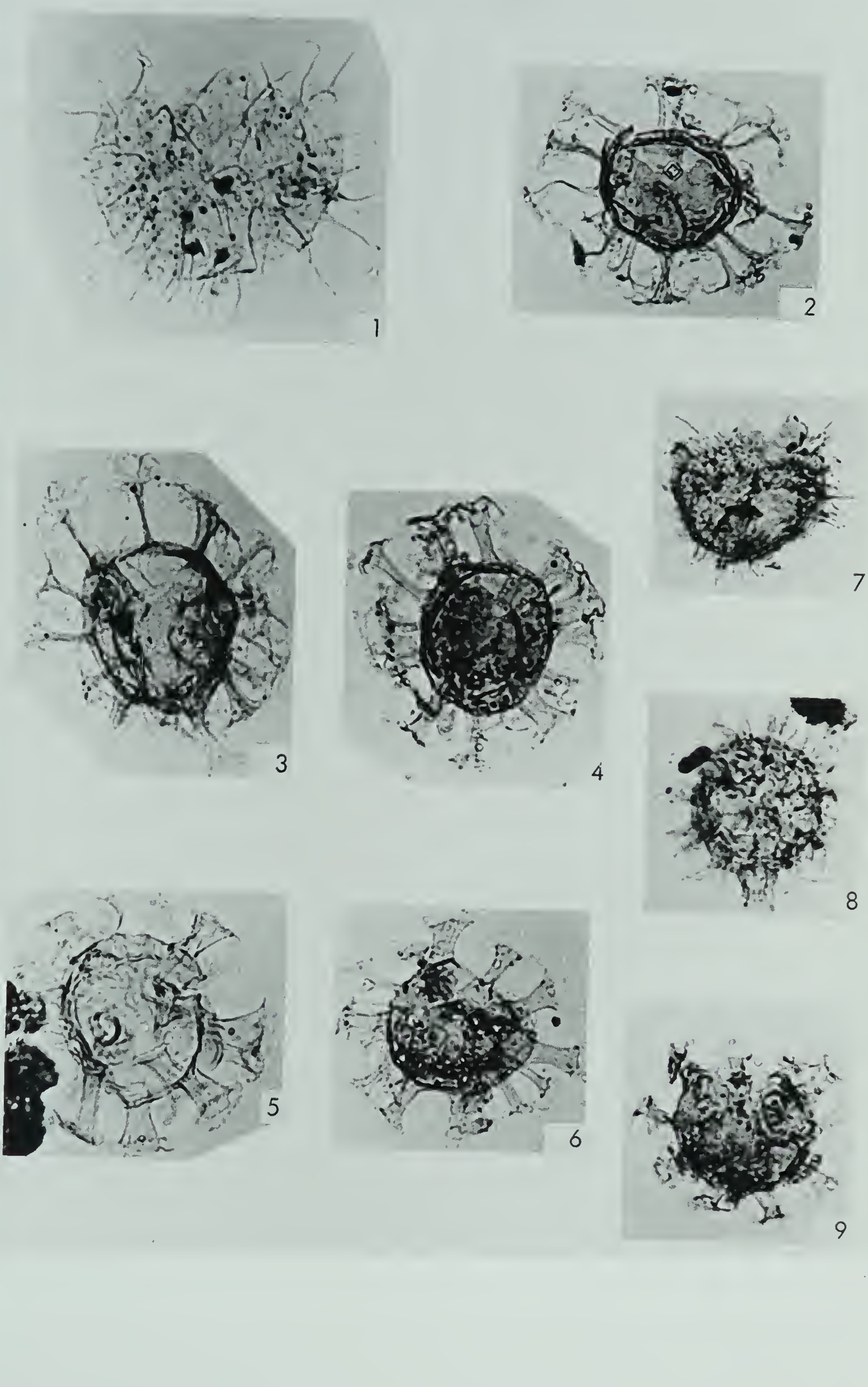

PLATE V

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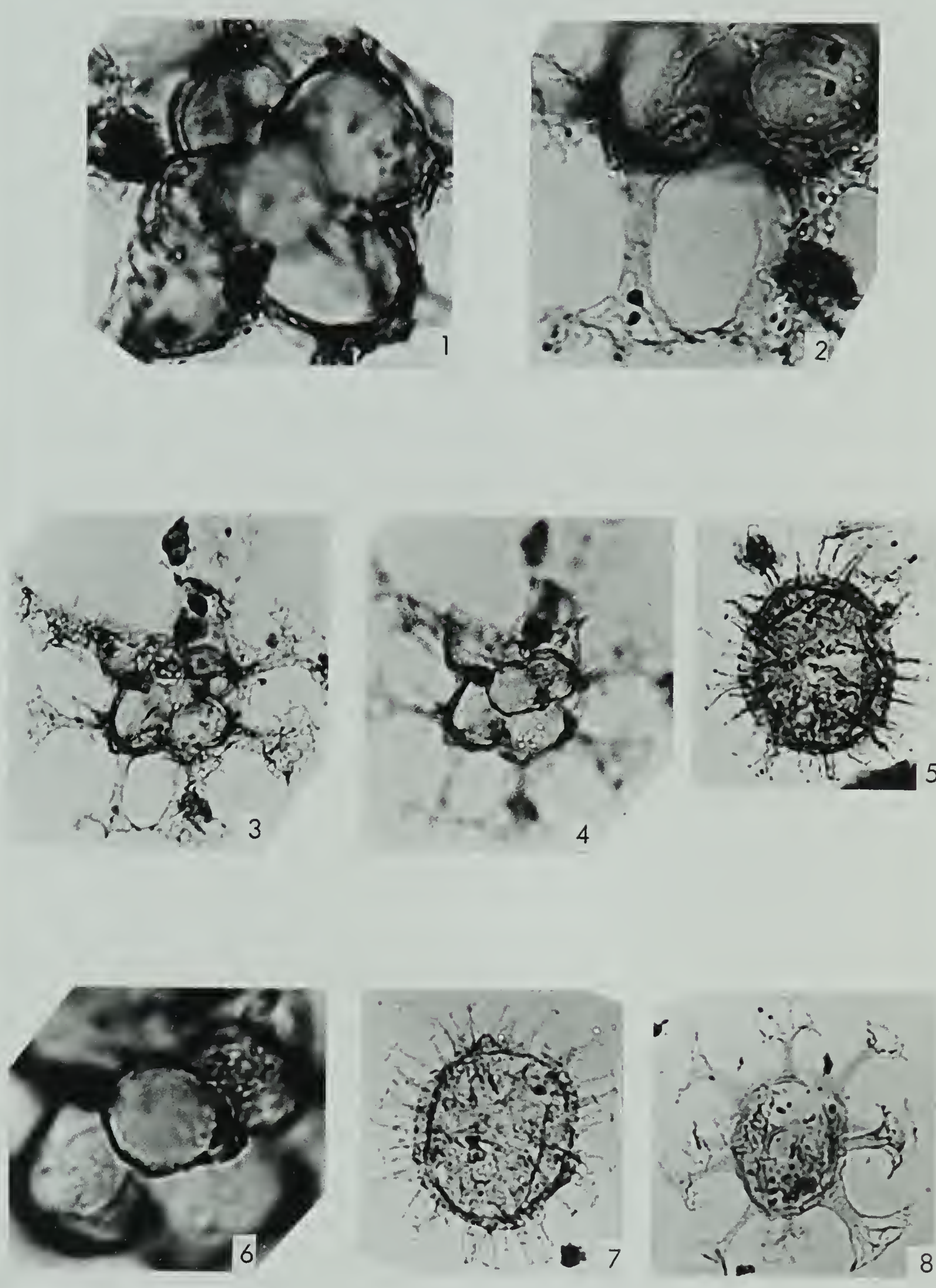

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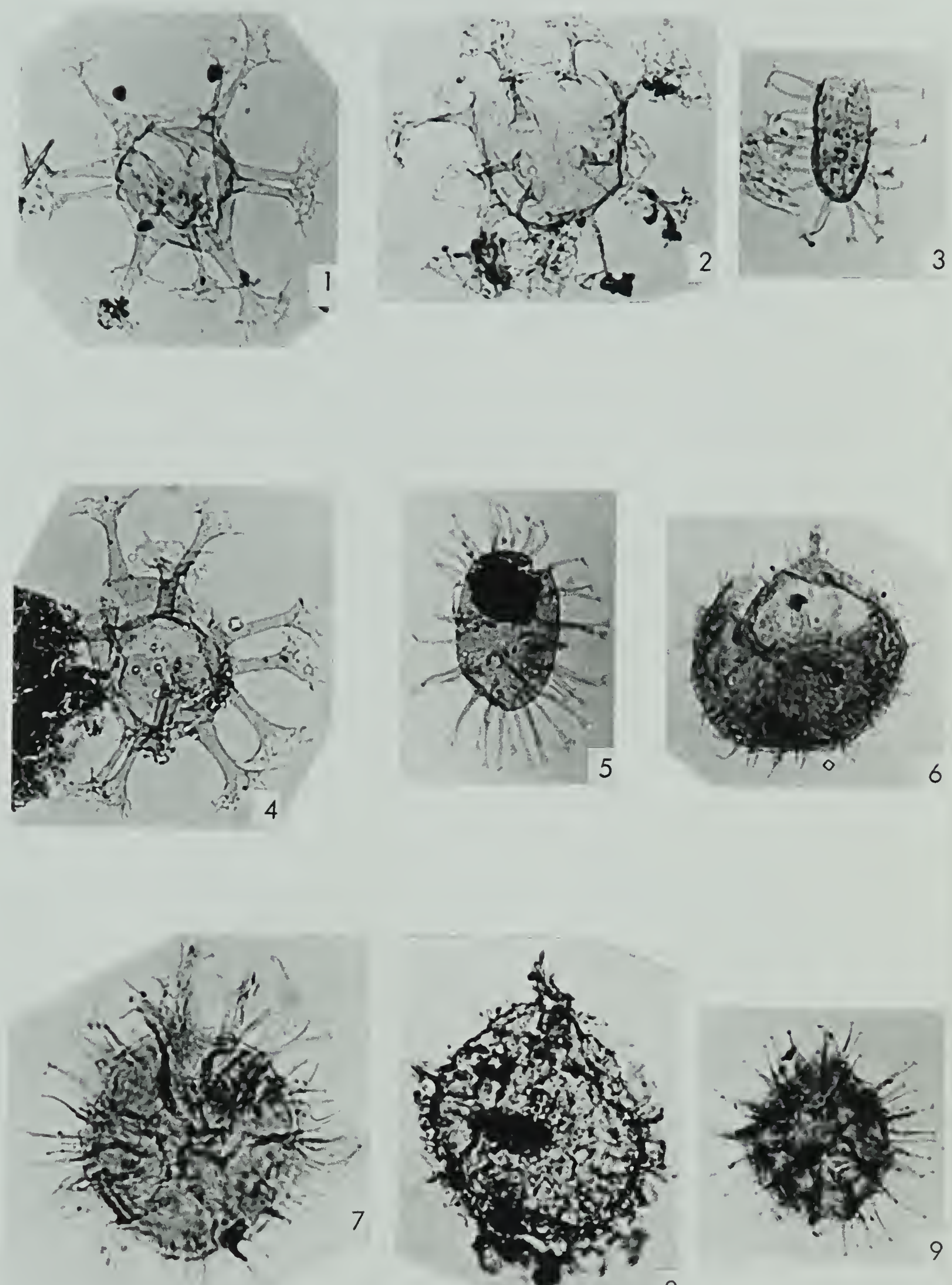

PLATE VII

All figures are at a magnification of x600 unless otherwise stated.

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PLATE VII

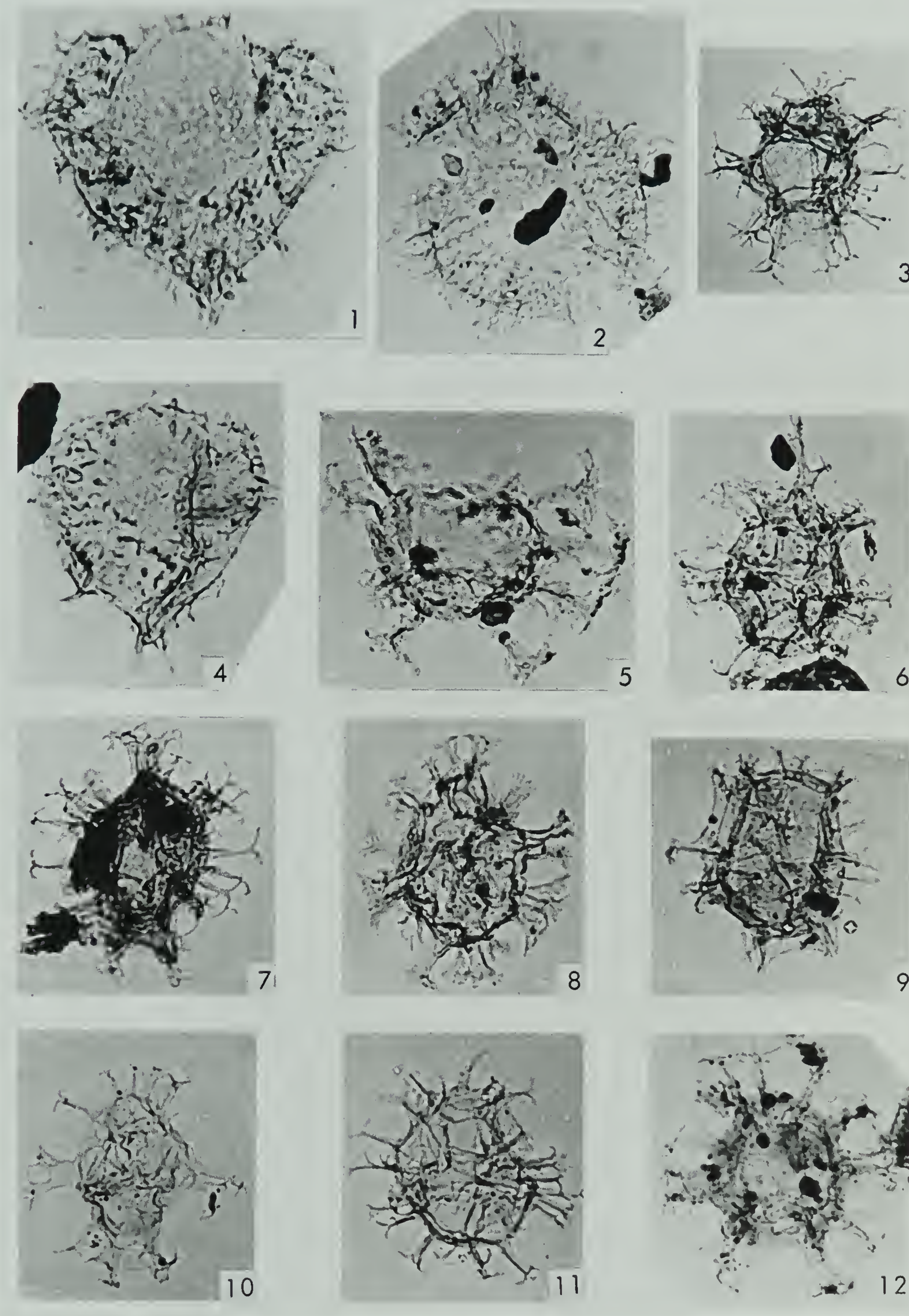

PLATE VIII

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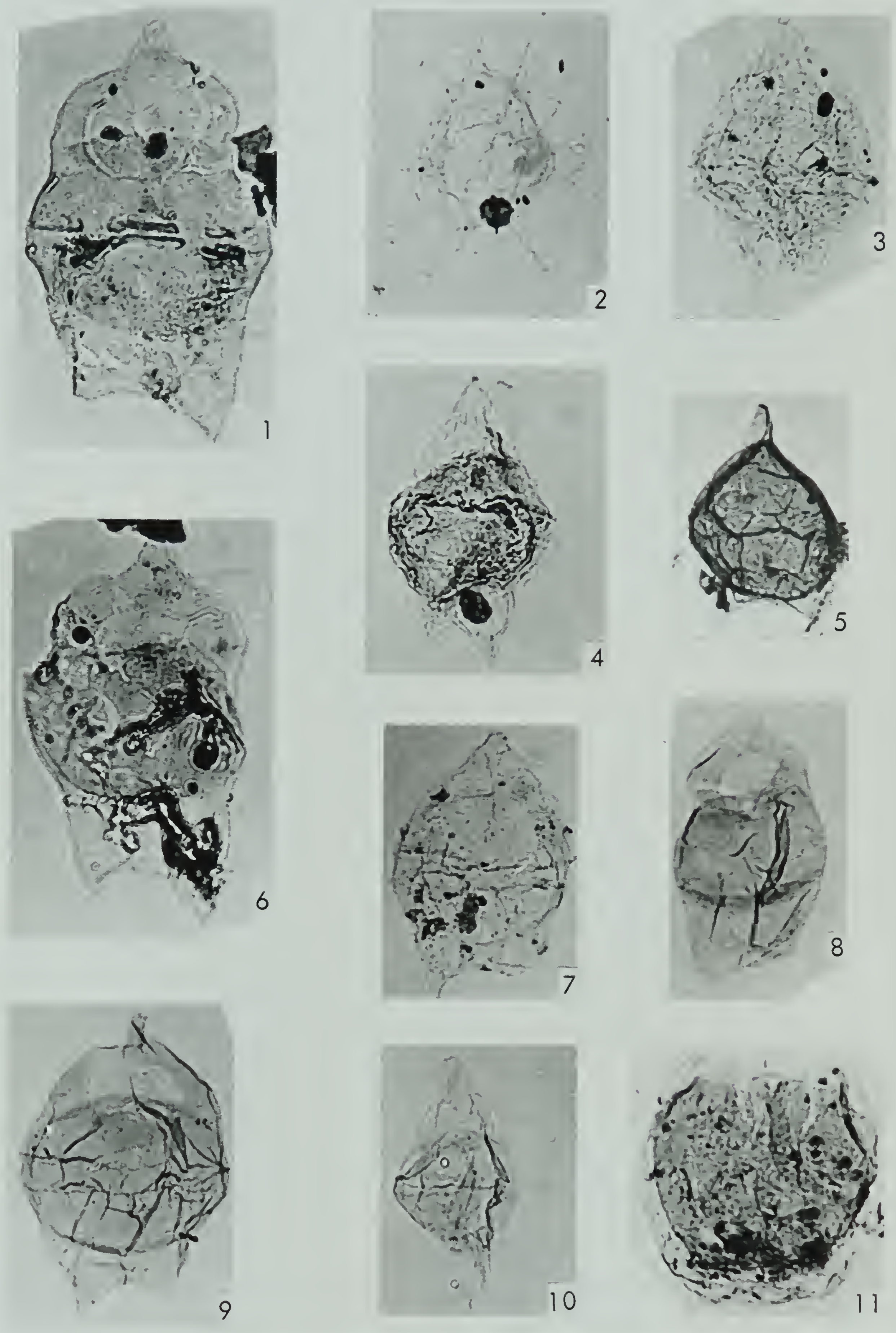

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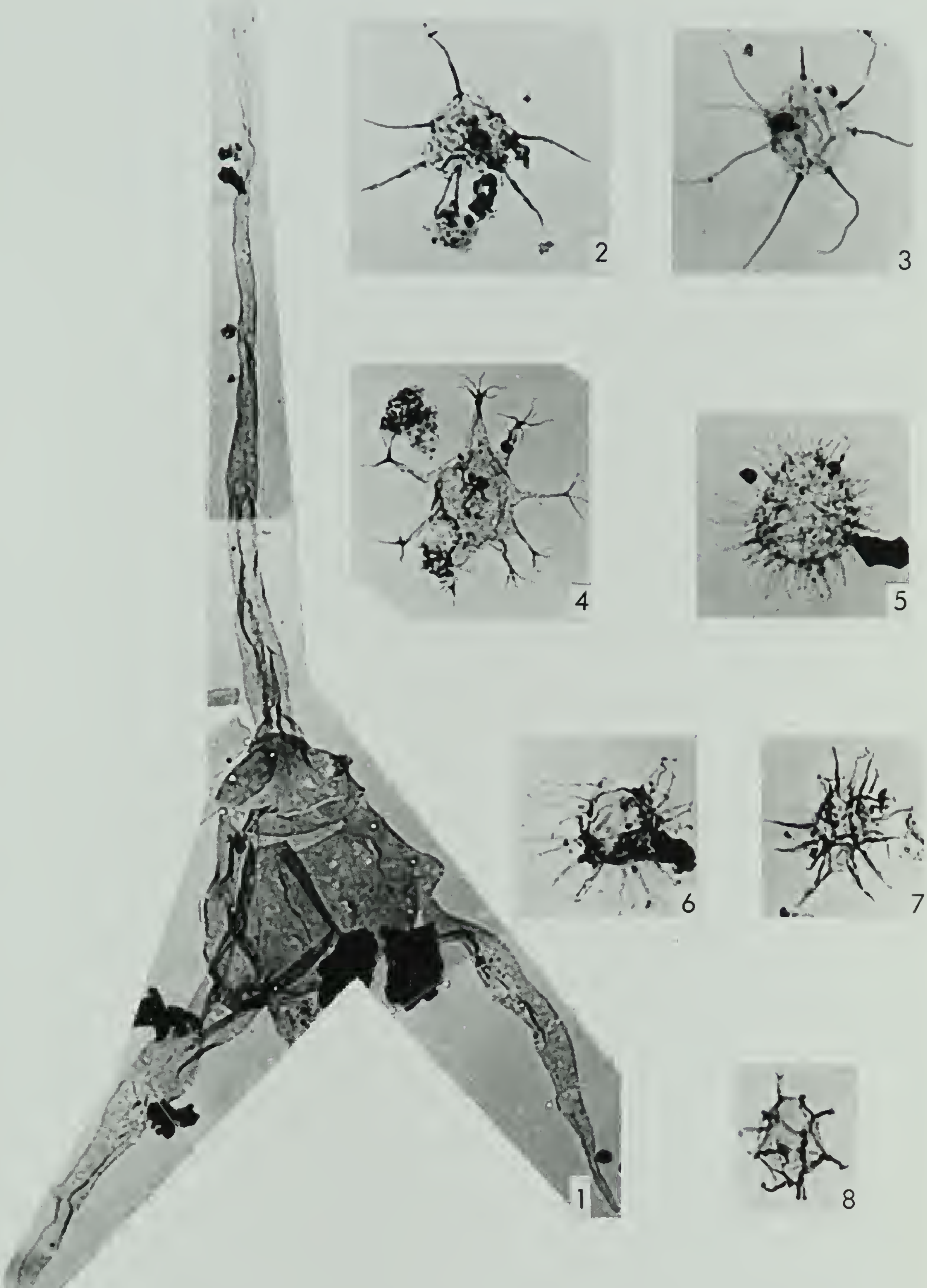

PLATE X

All figures are at a magnification of x600 unless otherwise stated.

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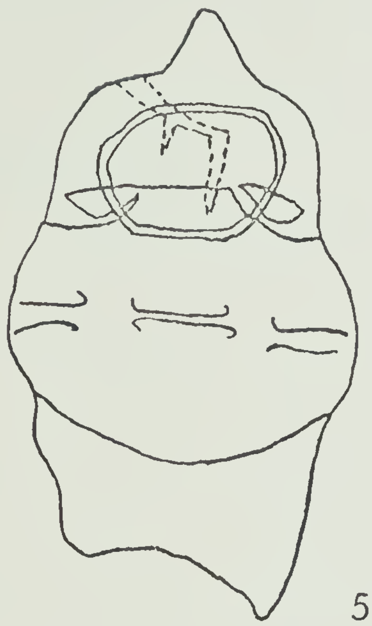
PLATE X



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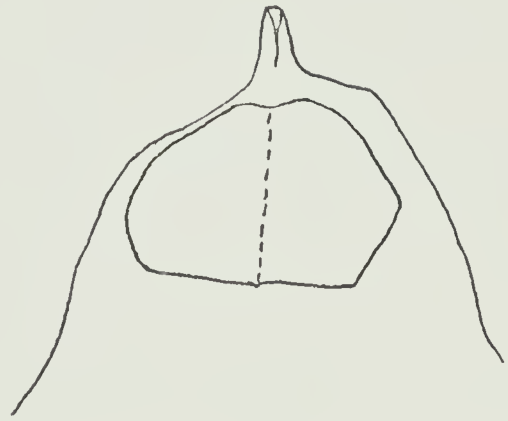

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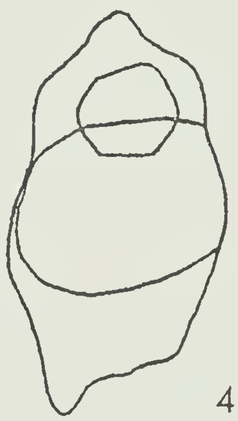

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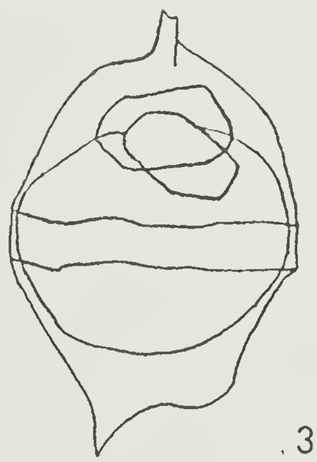

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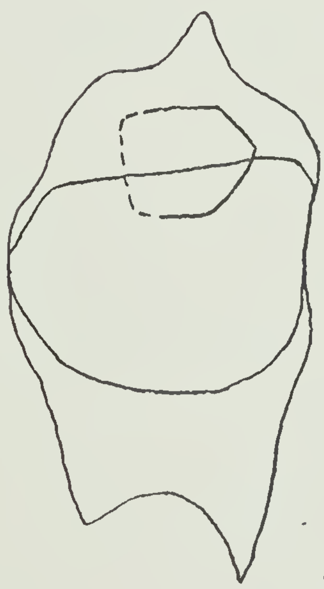

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APPENDIX A

Sample Localities

Sample Localities

Sample localities previously mentioned in the text are listed below with their code numbers, geographical locations, brief description and the number of samples processed from each.

Lethbridge Area

JW66-12; 'Coal Measure Locality', at Lsd.1, Sec. 2, Tp.7, R.22, W.4th Mer. Cut-off bank of meander exposing the Oldman-Bearpaw boundary and the lower 166 feet of the Bearpaw Formation. Minor faults are present. Sixteen samples investigated.

JW69-1; 'Side Gully Locality', at Lsd. 9-10, Sec. 33, Tp.6, R.22, W.4th Mer. Side gully on cut-off arm of meander, exposing approximately 60 feet of Bearpaw Formation. Five samples investigated.

JW66-13, RH69-13; 'Magrath Locality', at Lsd.15, Sec.32, Tp.6, R.22, W.4th Mer. Cut-off bank of meander exposing the Magrath Member and 180 feet of Bearpaw shale. Twelve samples investigated.

JW66-14, RH69-14; 'Kipp Locality', at Lsd.11, Sec. 19, Tp.6, R.22, W.4th Mer. Cut-off arm of river meander exposing the Kipp Member with 45 feet of Bearpaw shale. Eight samples investigated.

JW68-1, JW68-2; 'Cut-off Locality', at Lsd.10-15, Sec.24, Tp.6, R.23, W.4th Mer. 90 feet of Bearpaw Formation between the Kipp and Ryegrass Members. Six samples investigated.

JW66-16, RH69-16; 'Monarch Locality', at Lsd.12, Sec.34, Tp.9, R.23, W.4th Mer. Cut-off bank of meander exposing the upper Ryegrass Member plus 20 feet of Bearpaw shale. Folding and faulting prevalent. Two samples investigated.

JW69-2; 'River Locality', at Lsd.1-2, Sec.32, Tp.9, R.23, W.4th Mer. Approximately 38 feet of Bearpaw shale exposed in river bank. Three samples investigated.

Cypress Hills Area

JW66-2; 'Irvine Locality', at Lsd.6, Sec.31, Tp.11, R.2, W.4th Mer. Oldman - Bearpaw boundary and lower 25 feet of Bearpaw Formation exposed in creek. Three samples investigated.

JW66-1; 'Ross Creek Locality', at Lsd.12, Sec. 14, Tp.11, R.3, W.4th Mer. 170 feet of basal Bearpaw shale exposed along creek. Fourteen samples investigated.

JW66-9; 'Manyberries East Locality', at Lsd.6, Sec.32, Tp.5, R.4, W.4th Mer. 80 feet of upper Manyberries Member exposed in coulees. Eight samples investigated.

JW66-5; 'Lodge Creek Locality', at Lsd.7, Sec. 32, Tp.5, R.2, W.4th Mer. 100 feet of Bearpaw shale exposed in coulee. Eight samples investigated.

JW66-6; 'Highway 48 Locality', at Lsd.12, Sec.5, Tp.6, R.2, W.4th Mer. 75 feet of upper Manyberries Member exposed in road cut. Five samples investigated.

JW66-10; 'Willow Creek Locality', at Lsd.5, Sec.25, Tp.6, R.3, W.4th Mer. 100 feet of upper Manyberries Member exposed in creek. Eight samples investigated.

RH69-01; 'Fly Lake Locality', at Lsd. 1-2, Sec.7, Tp.8, R.3, W.4th Mer. One sample investigated. Exposure of Belanger Member, 20 feet of shale and top of Oxarart Member in hillside. Sample taken approximately 5 feet below the Belanger Member.

APPENDIX B

LIST OF THE POLLEN AND SPORE SPECIES RECORDED FROM THE BEARPAW FORMATION BY NORTON & HALL (1969) AND OLTZ (1969).

Norton & Hall (1969) recorded the following pollen and spores from the Bearpaw Formation of east central Montana:-

Aquilapollenites amplus Stanley

A. pulvinus Stanley

Cingulatisporites scabratus Couper

Concavisporites juriensis Balme

Cycadopites scabratus Stanley

Dicotetradites granulatus Norton & Hall

Ephedripites ovatus (Pierce) Norton & Hall

E. undulatus Norton & Hall

Erdtmanipollis cretaceus (Stanley) Norton & Hall

Gleicheniidites senonicus Ross

Hamulatisporis hamulatis Krutzsch

Kurtzipites trispissatus Anderson

Laevigatosporites gracilis Wilson & Webster

Lycopodiumsporites austroclavatidites (Cookson) Potonie

Momipites circularis Norton & Hall

M. parvus Norton & Hall

Monosulcites carpentieri Delcourt & Sprumont

M. latus Norton & Hall

Osmundacidites wellmanii Couper

Peromonolites granulatus Norton & Hall

Reticuloidosporites dentatus Pflug

Sequoiapollenites polyformosus Thiergart

Spheripollenites subgranulatus Couper

Spinomonoporites typicus Norton & Hall

Taxodiaceaepollenites hiatus Kremp

Tricolpopollenites clavireticulatus Norton & Hall

T. sp. 1

Tricolporopollenites granustriatus Norton & Hall

T. megaexactus subsp. bruhlensis Thompson

T. prolatus (Pierce) Norton & Hall

T. striatus Norton & Hall

Oltz (1969) recorded, in addition to those species recorded by Norton & Hall (op. cit.) and above, the following species of pollen and spores from the Bearpaw Formation of east central Montana:-

Abietineaepollenites microalatus microalatus Potonie

A. microreticulatus Groot & Penny

A. varius Oltz

Acanthotriletes levidensis Balme

Alnipollenites trina (Stanley) Oltz

Appendicisporites aff. tricornitatus Weyland & Greifeld

Aquilapollenites delicatus Stanley

A. pyriformis Norton

A. reductus Norton

Calamospora nathorstii (Halle) Klaus

Cicatricosisporites dorogensis Potonie & Gelletich

Circulina parva Brenner

Concavissimisporites variverrucatus (Couper) Brenner

Cranwellia striata (Couper) Srivastava

Cyathidites minor Couper

Hamulatisporis amplus Stanley

Laevigatosporites discordatus Pflug

L. ovatus Wilson & Webster

Leiotriletes pseudomaximus (Pflug & Thompson) Stanley

Leptolepidites major Couper

Lygodioisporites cerniidites (Ross) Bolkhovitina

L. sp.

Monosulcites crescentus Oltz

M. minutus Oltz

Osmundacidites comaumensis (Cookson) Cookson & Dettmann

Perotriletes sp.

Phyllocladidites mawsonii (Cookson) Couper

Pinuspollenites ruginosa (Stanley) Oltz

Proteacidites cerebriformis (Markova) Bratzeva

Rhoipites globosus Stanley

R. pisinnus Stanley

Rugubivesiculites reductus Pierce

R. rugosus Pierce

Schizosporis complexus Stanley

Spheripollenites scabratus Couper

Stereisporites antiquasporites (Wilson & Webster) Dettmann

S. psilatus (Ross) Thompson & Pflug

Striainaperturites variatus Oltz

Styx minor Norton & Hall emend. Oltz

Symplocoipollenites sp.

Tricolpites modulus Oltz

T. tectostriatus Oltz

Triplanosporites pseudosinuosus Thompson & Pflug

T. sinuosus Thompson & Pflug

Zlivisporis blanensis Pacltova